OUR WORLD

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A SKETCH OF ORIGINS
ACCORDING TO SCIENCE

BY

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MALVOLIO: I am not mad, Sir Topas: I say to you, this house is dark.

CLOWN: Madman, thou errest: I say, there is no darkness but ignorance; in which thou art more puzzled than the Egyptians in their fog.

—*Twelfth Night, Act iv, Scene ii.*

PREFACE

SOUND ideas relating to the public welfare are not effective until so generally shared as to guide public opinion. The essentials of physical science are the basis of all sound thinking. The more thoroughly and generally they are understood, therefore, the better for social, political and economic conditions. The sole purpose of this book is to present in as brief compass and plain terms as practicable the principal data of general science as now accepted, without exploiting special theories. If evolution appears to be the key to explanation of our world in all its phases it is because the evidence now admits of no other.

The chief difficulty in preparing such a book is the choice of materials from a vast and various mass from many sources. Yet this difficulty is somewhat lessened by the consideration that most of the details of science have been developed in the search for principles and in the application of those principles to practical uses. The arrangement follows the natural sequence, except that, for clearness, some general causes are stated in connection with specific phenomena; for the main divisions of science overlap and are governed alike by the laws of matter.

C. H. P.

CONTENTS

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CHAPTER I

COSMIC PHASES

THE SPECTRUM

THE spectroscope, devised by Kirchhoff and Bunsen in 1859, shows the elements of any object that emits light, whether a distant orb or a filmy nebula. It has solved the mystery of certain of the variable stars, made the sun a field of intimate research, and shown the direction in which the solar system is traveling. These and similar results have revolutionized astronomy and projected the theory of evolution through the vast of starlit space. The nature and functions of this instrument must be understood before the facts it has demonstrated can be fully appraised.

Light is a result of motion of or within the atoms of the matter affected and communicated by the ether supposed to pervade all matter and all known space. The presence of this ether cannot be proven by any method yet known. It exists in theory to account for the waves of energy—heat, light, and electricity—which are known and determined with extreme accuracy.

For many years dark lines across the various colors of the solar spectrum had attracted attention. They are called the Fraunhofer lines, from the name of the investigator who first made them the subject of serious investigation; but it was not until after the spectroscope came into use and the wave theory of light was generally accepted that the results were explained and applied to the solution of many problems of astro-physics. Spectrum analysis has thus become a leading factor in the modern science of astronomy and a powerful aid in physics and chemistry.

It has led to several improvements in the instrument which have added greatly to its value in the many uses to which it is put. The most important of these is in substituting a so-called grating in lieu of prisms. This grating is a plate of glass or speculum metal ruled with accurately spaced and parallel lines, in some cases with 60,000 or more to the inch—in itself an extraordinary mechanical achievement. The main purpose of these appliances is to lengthen the spectrum by diffraction in order to show all the lines, which number many thousands, but with as little loss of brilliancy as possible, since the difficulties of observation increase with the distance from the source of the light. The grating also permits an accurate count of the frequency of the waves—the number per second, which is of vital moment in many investigations; and considering the fact that the sensation of sight is produced by waves ranging from 400 million million to 800 million million, in round numbers, per second, the measurement and analysis of these waves rank among the greatest technical attainments of science.

The rays are admitted through a minute slit, say one-tenth of an inch long and one-thousandth of an inch wide, to pass through a lens making them parallel; thence to a series of prisms, an echelon of thin glass plates, or a grating, which transmits or reflects them through another lens by which they are focused a short distance in front of the eye or a photographic plate for permanent record and comparison with the results of laboratory investigation, so far as that is possible. The prisms, owing to lesser loss of light, are most used in astronomical work, in connection of course with the telescope.

Every element, when heated to the point of incandescence can thus be identified, under suitable conditions, as infallibly as a person by his fingerprints, for the spectrum of one element is never duplicated by that of another. When, therefore, it is found that a given element—iron or hydrogen, for example—shows certain characteristics by exam-

ination in the laboratory, its presence in a distant star or nebula will likewise be indicated. Investigations so conducted have established several results of decisive import in studying the constitution, evolution and motion of the stars and other astronomic objects.

The spectrum of an incandescent solid body, a liquid or a condensed gas is continuous, that is to say, the normal colors are not crossed by lines of any kind. The spectrum of an incandescent gas or vapor consists of bright lines arranged according to the different elements, or bright lines upon a faint continuous spectrum. If the light is from a source that would otherwise yield a continuous spectrum, but passing through gases or vapors less heated, dark lines are produced by absorption. When such a body is moving toward the earth or the earth toward it, the lines shift slightly toward the violet; and when the body is receding from the earth or the earth from it, the shift is toward the red. The rate of this change, as found by comparison with a similar spectrum of a stationary light, affords data from which the speed may be calculated. By this method the velocity with which stars and comets are moving, the orbits of the variable stars, the path of the solar system and many other motions involved in the problems of celestial mechanics are determined. And be it understood that these conclusions are not theories, but facts as provable as any in physical science. They are the effects of the laws of light, which inevitably follow from the nature of light itself.

Light radiates through free space—as from a star to the earth at the rate of 299,800 kilometers (186,330 miles) per second, the velocity being calculated with a precision correct within 30 kilometers. This amounts to about 6 million million miles per year. The stars are all at such great distances from us that the unit of measurement is called a "light-year," the distance that light travels in a year. The nearest lucid star, Alpha Centauri,[1] in the southern hemisphere, is about 4½ light-years from the sun; the next

nearest, a catalogue star (21,185 Lalande), in a different direction, is 7; and Sirius, the brightest of all the stars, in a yet different direction, is 9. The average distance between neighboring stars, so far as their distances have been calculated, is from 6 to 8 light-years; and probably the remote stars are similarly spaced, except where there are groups or clusters of stars comprising systems. This average, of course, is only a rude generalization, for the variations are many and enormous.

To ascertain the distance of a star is one of the most delicate and difficult measurements in astronomy. The method thus far employed is that of triangulation, the same as that used by surveyors in topographical work. The conditions create the difficulty. The angles can be determined only by the parallax—the apparent change in the position of a star produced by the change in the position of the earth in its orbit around the sun. The base line of this measurement is the diameter of the orbit, about 186 million miles. Yet this is too short to afford a basis for calculating the distance of only a very small proportion of the stars. Even some of the brighter ones are so far away that an appreciable angle cannot be defined. Recently such progress has been made in estimating stellar distances by means of the characteristics and degrees of light from variable stars in clusters so far distant as to show no parallax that there is some prospect of perfecting methods that will also determine the distances and dimensions of stars that are not variable. These methods are a development of spectrum analysis.

A FINITE UNIVERSE

The total number of stars visible through the greatest telescopes is somewhat less than 200 million, though the number that can be photographed is much greater. It is mathematically certain that if the brilliant stars were infinite in number, and light suffers absolutely no diminution in passing through space, the entire sky would be suffused

with a glow. There is no evidence as yet that light is so diminished; and there are substantial reasons for thinking that the number of stars is limited. Astronomers are almost unanimously of opinion that the stellar system which constitutes our universe is not infinite, but is limited in all directions. The evidence indicates a spheroid formation, much flattened, the northern hemisphere of which is not coincident with the vista presented by the skies of the earth's northern hemisphere, the plane of the equator forming an angle of about 62 degrees with the plane of the Milky Way.

This conception is founded upon the most thorough observations possible to make. The total number of stars shown by photographs of all the stellar regions reveals a progressive decrease away from the Galaxy, while through the Galaxy the distance is so great that the stars more remote cannot be resolved by the most efficient instruments; yet the spectroscope shows unerringly that the glow in the outlying and impenetrable regions is light from condensed bodies. In other words, if the average number of stars per unit of space is the same in the Galaxy as it is toward the poles, the effect we behold would be produced by the greater distance through it—the greater extension of the equatorial plane of the spheroid.

No other theory accounts for the phenomena; and it is aided by the present position of the solar system. The fact has been established that the sun and its retinue are moving in the general direction of the constellation of Lyra, near the present position of the magnificent Vega, a star of the northern hemisphere. The speed of this motion is about 19 kilometers per second. A simple calculation will therefore show that the early history of the earth, even of the human race, was passed in a vastly different region of the universe from that through which it is now voyaging.

Yet the velocity of the sun is very much less than that of most of the stars, so far as their motion is known. The average speed has been estimated at 26 kilometers per second; but such an average has small significance because of

the enormous variations from it. Some of the stars are moving at such a rapid rate as to forbid any idea of relation, except in those cases where similarity of speed and direction among a group of neighboring stars indicates a separate system. The beautiful Arcturus was long supposed to have the greatest velocity of any star—between 200 and 300 miles per second. Even in ancient times its change of position was noted by the diligent students of the heavens. Modern astronomy, however, has found that this speed is exceeded by several other stars of telescopic order. It has often been remarked, as illustrating the vastness of stellar distances, that notwithstanding the movement of all the stars if the astrologers of antiquity could now survey them they would detect no considerable changes in the constellations with which they were so familiar.

In studying the possibilities of the celestial mechanism, the diversity of direction in stellar motion is a fact of much importance. Efforts have been made to find evidence that the movements of the stars are governed by some sort of universal concert; but they have thus far been unavailing on anything like a general scale. Two great streams in opposite directions, but parallel with the galactic plane and perhaps other streams, are thought by some observers to be shown by transverse motions; but these conclusions embrace but a small proportion of all the stars. In any event, there remains a diversity of movements that cannot now be brought into any semblance of system or coördination.

It would seem remarkable if there were no star streams. If the spheroid conception of the universe be true, whatever may be irregularities of the exterior, there must be a cause or combination of causes, and the only causes now conceivable are gravitation and momentum. If the solar system be near or within easy view of the central region, the conclusion is obvious that the planetary type of motion does not propel the stars around a central body. In fact neither the sun nor any of the stars, the proper motion of which has been determined, reveals an orbit. Measurements

have not been conducted long enough; and it may require many centuries of observation before sufficient data can be accumulated to determine with any assurance whether stellar movements have an orbital character.

There are, of course, many stars very much larger than the sun; but this difference is more of extension than of mass. The largest known stars are greater than the sun, in most cases, mainly because they are in a more diffused or gaseous condition, which contracts with age. Again assuming our universe to be finite in extent, it may be readily imagined that the ether or other medium of radiation does not extend indefinitely beyond the outer stars; hence there would be no ultimate loss of potential energy by dissipation into space. Inasmuch as the universe shows no signs of condensation after the lapse of inconceivable time, the problem is narrowed to the principle of perpetual motion, which appears to actuate the material universe in the atom and at large; and this problem may lie in the realm of the unknowable.

EVOLUTION OF STARS

Armed with the spectroscope, astronomers were not slow to apply the theory of evolution to the stars. The evidence was so suggestive that the principle gained general recognition. The universality of the laws of gravitation and radiation was supplemented by the discovery that the elements and properties of matter are the same wherever matter exists in the universe. These elements do not always exist in the same combinations, and it is not apparent that all of them are in every astronomic body. Thus certain elements exist on the earth that are not known to be in the sun; and certain other elements are in some of the stars and nebulæ that are not known to be in others. These facts are shown by the spectroscope; indeed, there are many lines in some of the spectra that are not yet identified. These discrepancies are the subject of unremitting research and will doubtless eventually be accounted for. Without

pursuing this highly technical branch of science further, it suffices to say that the unusual and unknown elements form but a small proportion of the masses of matter scattered through the cosmos; hence the assumption is entirely safe that the material universe is as homogeneous in its constituents as it is in its laws. This leads to the conclusion that the evolutionary processes of the stars are general, the results varying with the conditions. If, therefore, it can be determined what the several stages are, we may form a definite conception as to the origin of the solar system and of the earth itself. This has naturally become the paramount object of astronomical theory and research. That great progress has been made will be manifest by an untechnical recital of the leading facts which the telescope, the spectroscope and the camera have demonstrated.

Any theory of stellar evolution is confronted at the outset with two formidable obstacles: the remoteness of the stars and the duration of time required for their successive periods of development. As the former has, in some degree, been surmounted by optical aid, so has the latter by the great number of stellar objects representing all the stages through which matter passes in being organized into stars and systems, excepting the lesser features of planetary character, which probably exist in immense numbers, though invisible. Within the entire range of the intellectual faculties there is nothing approaching in sublimity the ideas evoked by this wondrous panorama, viewed as stages in the evolution of worlds.

MULTIPLE STARS

There are now known about 150 stars that are variable in brightness because of partial eclipse. In each case an obscure companion passes at regular intervals between the star and the line of sight. Of this class, Algol is usually taken as the type of a very significant phenomenon; hence some details concerning it will be illustrative. It has long been known as the demon star (that being its name in

Arabic), owing to its plainly visible wink, during which it changes from about the second to nearly the fourth magnitude for a short time during every period of 2 days, 20 hours, 48 minutes and 55 seconds. The star is somewhat more than 1,000,000 miles in diameter, and the companion about 800,000, a little less than that of the sun. The distance between the two is somewhat more than 3,000,000 miles, and their combined mass about two-thirds that of the sun. At long intervals occur slight irregularities in the rhythm of the variations, which have been ascribed either to the revolution of both bodies around a third invisible one, or, more probably, to perturbations caused by the attraction of other members of an invisible system.

In all instances of the Algol type the essential features are similar—a light and a dark or less brilliant body producing a periodical eclipse because the plane of the mutual revolution happens to lie in the line of sight. As this phenomenon is possible only because of the accident of position and the fact that the two bodies are relatively near together, there are undoubtedly great numbers of unknown binaries of the same type which cannot be detected. Moreover, the presumption arises that the visible stars form but a comparatively small part of the entire number of stellar bodies comprising the universe. There is, of course, no way to reach even an approximately reliable estimate as to the proportion; yet some eminent authorities have expressed the opinion, based upon the motion of the visible stars impelled by universal gravitation, that they number at least four or five dark bodies to every one that is luminous. The proportion, however, is not very important to the general theory of evolution. It is enough to know that dark bodies are numerous and that in earlier stages they were incandescent, having lost their light through radiation; and unless the universe is slowly running down—a rather irrational thought, in view of the great number of nascent stars—they are awaiting the action of conditions and forces that may sooner or later revive their dormant energies.

Another type of binaries which perfectly illustrates a stage through which Algol's companion has passed is the star known as Beta Lyræ, in the same constellation as Vega and at intervals nearly as brilliant. This also is composed of two stars revolving around a common center of gravity in an orbit directly in the plane of vision. Both are still in a highly gaseous state, the mean density of the system being a little less than that of our atmosphere. The larger of the two is about twice the mass of the smaller, and, as might be expected, is only about one-half as bright, doubtless owing to the greater rapidity that marks the evolution of the smaller bodies; yet the mass of the main star is nearly ten times that of the sun. The centers of the two bodies are about 30,000,000 miles apart. As these figures are based solely on results of the spectroscope, they are only approximate, but no doubt are accurate enough to afford a fair idea of the material facts. Both bodies being bright, they are more brilliant when seen side by side than when one is behind the other, and therefore present the appearance of a variable star at regular intervals. The number of binaries of this type is very large.

A still earlier phase of stellar development is clearly shown by a large number of stars of the U Pegasi type. Here are two bright gaseous bodies either in contact or nearly so. This condition is more difficult to observe, particularly in remote stars, because when the lines of the spectra are not sharply defined precise calculations cannot be made; yet it may be a common process by which binaries are formed, resulting from the rapid rotation of a huge body in a rarified state. It first becomes a pear-shaped mass, which then divides into two separate bodies of unequal size. These tend through tidal movements and condensation to draw farther apart until a stable distance is reached according to the law of gravitation. And here would seem to be the mainspring of the mechanism that prevents the consolidation of nebulous matter beyond the limits fixed by its physical constitution. Evidently, matter can combine only so long as

the power of gravitation is greater than the momentum of revolution—centrifugal force; and that gaseous bodies revolve at higher rates of speed after consolidation sets in, and because of it, is apparent from the fact that all the stars, like the sun, in their gaseous stages are spheroids through physical necessity. If two or more bodies collide the heat generated resolves their masses into a gaseous condition in which the former processes are renewed. This may be so or not; but the hypothesis is as reasonable as any that can be formulated in the absence of positive knowledge. "The system," says Campbell, "would not run down until all the kinetic energy had been converted into heat, and all the heat generated had been dissipated. This would not occur until all material in the universe had been combined into one body, or into two bodies in mutual revolution. However, if there are those who say that the universe in action is eternal, through the operation of compensating principles as yet undiscovered, no man of science is at present equipped to prove the contrary."

These three types of binary stars, variable because of the character and motion of their components, exist in all manner of gradation, as might be supposed from their number and apparent differences in age and composition. Besides these types, tens of thousands of other double stars are disclosed by the telescope. With these, the orbits are not in line of sight, hence they appear merely as double, where both are luminous. In many cases one or both of the components are also double. In addition to the vast number of stars known to be binaries, it is thought by competent authorities that nearly one-half of all the other stars that appear single are really double. In any event, the phenomenon is so common in all quarters of the universe that it must indicate the normal course of evolution in conditions that are very general.

That such conditions have existed on an immense scale in diverse regions is shown by the fact that, besides the pairs of stars, there are very numerous systems composed of

from three stars to clusters containing many thousands. For example, Mizar and Polaris are triple. Castor and many others are quadruple. Theta Orionis is one of a system of six, and Epsilon Lyræ, of seven. The Pleiades, whose six most visible stars are known to every one who has the slightest acquaintance with the northern skies, have also several thousand telescopic members all moving together in the same general direction accompanied by a more or less nebular environment visible by reflection and possibly in the way of being gradually absorbed, or, as some observers maintain, the product of stellar dissolution.

These systems exist in every variety; stars of every order of brightness are combined in every way; and in many clusters the proportion of variable stars is large. Even the larger clusters are varied in form and constitution. Some are small and irregular both in outline and in the distribution of the stars, like Pleiades, while others are enormous, like the Magellanic clouds in the southern skies, resembling in their general appearance the character of the Milky Way. Other clusters, to the number of several scores, are globular, and their components are arranged with considerable regularity, like the aggregation in Hercules, which to the naked eye is a luminous cloud, but is resolved by the telescope into thousands of stars, each one a sun. How all these clusters assumed and maintain their present character are secrets for the future to solve.

Recent investigation of star clusters, however, has already greatly advanced the state of knowledge concerning them. One important result has been to confirm the probability that all the known clusters belong to the sidereal system of which the Milky Way is the principal evidence. But this result has also greatly enlarged prior conceptions of the size of that system. The dimensions of the greater clusters are so vast that the stars composing them are scarcely nearer to one another than those of our own region of the skies. The relatively slight attraction of bodies so far separated is evidently balanced by their motion, and this, in

general, prevents any group or cluster from coalescing through gravitation.

STAGES OF STELLAR EVOLUTION

Important as are the results so far attained through the study of the variable stars, similar investigations of the physical nature and stages of stellar evolution have been even more fruitful of definite knowledge. So many stars of every variety are within reach of optical examination that the study has been conducted by many astronomers and physicists with unflagging zeal and brilliant achievement. These cosmic phases are rapidly assuming the aspect of an exact science; but they are so diversified, so complex and so technical that in a general sketch only the more salient features may be presented.

The red stars are at the extremes of the scale of classification. They are the youngest or the oldest, not necessarily in time, but in the stages through which they have passed; for obviously the stages of evolution of a small star would be shorter than those of a large one—the heat would sooner be dissipated. Yet the red stars, to be visible for the immense distance their light must travel, must have gained or retained a considerable degree of brightness. If a star is not in a brighter stage than Jupiter, of the solar system, it is totally invisible; not even the dark companions of the double stars can be seen by reflected light. At best, therefore, in studying the evolution of stars, direct knowledge cannot extend much beyond the point where consolidation has reached the state of incandescent gas. But fortunately from this point the members of our own system unquestionably illustrate aptly enough the later phases of all stars that have lapsed into invisibility.

In recent years the spectroscopic study of the stars has developed a generally recognized gradation into classes ranging from blue to dark red. This is the usual way of arranging them in the order of the successive phases through

which they pass from youth to old age. This classification, however, is not sharply defined, since the various types shade insensibly into one another. Thus between the dark red and the reddish yellow and the yellow and the light blue stars the tints are very numerous. The spectra of the great majority of stars are continuous, except for dark or absorption lines, which increase steadily from a few for the blue stars to many for the red, of the old or dwarf stars. In their early stages, whatever the degree of brightness, the stars are so diffuse and therefore of so much greater size that they are called "giants." This condition distinguishes them from the older "dwarfs" which have shrunk through condensation. It is supposed that the length of time required for a star to gain its maximum brightness is much less than for it to expire. This subject is yet a difficult problem, but it is of profound interest, as the existence of life on the earth depends upon the continuation of the sun's heat at not very much less than the present degree.

The changes in the spectra of the stars as they pass through successive stages suggests the inquiry, Why do not the elements shown in the older stars appear also in the younger if they are present, as they must be potentially at least? The answer invades the most obscure province of physical chemistry. "The conditions," says Campbell, "in the nebulæ and in the youngest stars are such that only the *simplest elements* like hydrogen and helium, and in the nebulæ nebulium, which we think are nearest to the elemental state of matter, seem to be able to form or exist in them; and the temperature must lower, or other conditions change to the conditions existing in the older stars, before what we may call the more complicated elements can construct themselves out of the more elemental forms of matter. The oxides of titanium and of carbon found in the red stars, where the surface temperatures must be relatively low, would dissociate themselves into more elemental components and lose their identity if the temperature and

other conditions were changed back to those of the early helium stars. There is no evidence, to the best of my knowledge, that the elements known on our earth are not essentially universal in distribution, either in the form which the elements have in the earth, or dissociated into simpler forms whenever the temperatures or other conditions make dissociations possible or unavoidable."

The sun may be taken as the best standard for comparison. It is a yellow star—in middle-age, so to speak. Its average density is one and one-half times that of water. Its equatorial diameter (865,000 miles) is much less than it was at the time its planetary system originated, as shown by the fact that all the stars of the early types average many times larger and are correspondingly less dense. By reason of gravitational pressure, the core of a star is necessarily much more compact than the outer parts and also heated to a much higher degree, which serves during the youth of the star to more than compensate the exterior for its loss by radiation. When the maximum external heat has passed and begins to fall, the bright lines that cross the spectrum of a star of an early type—showing an extremely high temperature of the gaseous envelope, the outer part of which is usually hydrogen—give way to the dark lines, which increase during the time that the star is bright enough to yield a spectrum. As the atmosphere becomes cooler and denser the complex spectra of the metallic oxides make their appearance. And this is true notwithstanding the fact that the internal temperature of the star must still be very high. The convection currents from within outward are less free as the body contracts. And this condition is the probable explanation of a type of variable stars in which the changes in brightness are not due to the causes already stated. These changes, while more or less rhythmic, are not strictly regular, and are therefore supposed to be caused by physical convulsions (radiation pressure) somewhat akin to those manifested by the so-called sun-spots, but on a much more extensive scale.

Another general fact bears strongly on the theory of stellar evolution. The average velocity of the forward movement of stars in the early (helium) stage is much less than that of the older (hydrogen and solar) stars; and the speed of the latter is less than that of the later types. Moreover, the components of the early double stars are so close together that they cannot be visually separated, while those of the later types are more and more widely asunder. The mutual revolution of the early pairs may occur within a few hours; with the later types, it often becomes hundreds of years. These movements are unquestionably the normal results of gravitation. Likewise newly formed stars do not elongate and divide when their size, composition and mode of formation do not compel the paired type of development. Assuredly the same general laws underlie both classes of phenomena; and the same general laws undoubtedly compel the aggregation of clusters on one hand and the dissociation of pairs and groups on the other, when the proximity of other bodies or systems exert their gravitational force. If science has established one conclusion more absolute than another it is that no phenomenon is haphazard, but is produced by a cause or combination of causes obedient to the fixed laws that govern matter. Evolution is the natural sequence of cause and effect through the operation of the laws of matter upon the conditions present.

It must not be understood that the opinion of astronomers is unanimous that the course of stellar evolution here outlined is proven beyond doubt; but it is clear to anyone familiar with the trend of astronomic theory that the opinion of the great majority of those most competent to judge is that the facts, so far as known, point to evolution in the reversing order of color and brilliance. Nor is it to be understood that there are no apparent exceptions to this order. There are phenomena which do not readily fall into classification and which science is not yet able to explain. But when we consider the shortness of the time during which current conceptions of matter and motion have guided

the study of astronomy, it is not strange that the manifold aspects of the universe at large, with the tremendous difficulties in the way of investigation, still present problems that resist solution.

NEBULAR STARS

Any attempt to explain the origin of the earth must be preceded by investigation of stellar development, and this in turn by inquiry into the probable formation of stars from nebular material. The latter is even more speculative than the evolution of the stars as such; and we are obliged not only to regard the known facts, but to consider the most reasonable theories that account for them, though the proofs yet lie on the confines of science.

Unlike the stars that challenge the notice of the most casual observer, the phenomena of the nebulæ are made known only by the combined use of the telescope, the camera and the spectroscope. On a clear and moonless night a good eye may perceive some of these objects as irregular patches of dimly diffused light, which reveal nothing of their true character. Even observation through powerful telescopes finds little more. Only prolonged exposure of the photographic plate, far more delicately sensitive than vision, discloses the formation and structure of these obscure objects. Thus they are permanently recorded for comparison and analysis. Owing to their peculiar fitness for photographic reproduction, they permit excellent pictures to be made. Some of them may be found in most works on astronomy. Examination of the various and spectacular forms they reveal will engage every thoughtful mind unfamiliar with what may be styled the protoplasm of the cosmos.

The spectroscope gives the explanation that the photographs suggest. It shows these cosmic clouds to be composed, for the most part, of the familiar elements of matter in a highly diffused state. If they are the disintegrated materials of former bodies, this is precisely the character they would disclose. If they are the diffuse beginnings of

future stars, their number should be very great; and so it is. As the stars show great diversity of age and state, the nebulæ—if such be their source—should manifest a similar variety of condition; and so they do. From the multifarious character and composition of the stars, there should be a like diversity of nebular types; and such is the fact. These types, as might be expected from their tenuous nature, are not so readily classified as the stars, yet they fall into fairly definite order. As with the stars, the characteristics of some of the nebulæ are not fully understood; but enough is known to justify confidence of opinion that here are the beginnings of stellar evolution in all its variety, since they suggest the probability of automatic processes by which dark bodies, extinct in every function save that of motion through space, are transformed from inert but potential matter to renewed dynamic energy, thus entering upon a new cycle of solar and planetary existence.

Between the youngest stars and mere nebulæ is a class so plainly sharing the nature of both states that the phase of transition is unmistakable. These interesting objects are styled the Wolf-Rayet stars, from the French astronomers who first discerned their peculiarities. Were they stars in course of gradual dissolution, as some observers have suggested, they would probably appear very much as they do. They project various combinations of continuous spectra and bright bands, thus proving condensed cores surrounded by extensive atmospheres at high temperatures. However, the suggestion that the phenomena indicate dissolution has no substantial reason to support it, except the high rate of speed at which this class of stars travel. On the contrary, all the facts, direct and analogous, so far as they have been determined, point to the opposite conclusion, which is generally accepted. These stars, which are relatively few (about 110 are now known), are well within the boundaries of the Milky Way and the Magellanic Clouds.

Apparently the phase of development preceding the Wolf-Rayet stars, in some instances, is that of the so-called plan-

etary nebulæ. These objects show a greater resolution of their materials into a gaseous state, yet possessing enough consistency in the central mass to produce a more or less spheroidal shape, though differing somewhat from one another in form and general arrangement. In some of them the central mass is encircled by a well-defined nebulous ring or shell. The number of this class is about the same as that of the Wolf-Rayet stars; but closely akin to them are several score of stellar nebulæ, which doubtless belong to the same class, any difference in appearance being due to their greater distance. Most of them are scarcely distinguishable as stars proper, because of their hazy appearance. Photographs, however, reveal their irregular dimensions, not widely extended, but quite compact, though entirely gaseous, as shown by the spectroscope. Like the Wolf-Rayet stars, the planetary and stellar nebulæ evince an affinity for the Milky Way; the great majority are within it and the others not far removed. The reason for this—and evidently the fact is too general to be the result of mere chance—has not been divined.

If all the Wolf-Rayet stars do not pass through the preliminary stage of planetary nebulæ, the explanation is the probable difference in the conditions that produced them; but the conditions are supposed to differ in degree rather than in character. The cause is found in the most spectacular phenomena, except the great comets, beheld in the heavens—the Novæ. As their name implies, they have the appearance of new-comers among the stars. Their brilliant but brief appearance has been a source of wonder through many centuries, the first one recorded being in the Chinese Annals of 134 B. C.

If a huge dark body, an extinct star, were to pass with great velocity through an expanse of dark nebulous matter (which is supposed to exist in many regions, such as the Coal Sack and great patches elsewhere in the Milky Way, obstructing the light of stars beyond) concentrated into particles or small bodies, the impact of myriads of meteor-

like bolts would bombard the surface into incandescence—the sudden flare of brilliance that heralds the nova. If the obstruction were not resistant enough to disturb the internal structure, the light would soon fade away. If, however, the cataclysm were wrought by the collision or close approach of two great bodies, the immediate result would also be the flash-star; but the subsequent phases would differ. The violence in either case would cause such disruption and heat that one or both of the bodies would be dissipated into gas, and a field of irregular nebula would mark the scene of the catastrophe. Precisely this phenomenon has been repeatedly observed.

Obviously, a great variety of results might appear, depending on the degree of energy awakened in the slumbering mass and on the precise manner in which the disturbance was produced. Such conceivably were the causes of the planetary and stellar nebulæ, which, like the Wolf-Rayet stars, are moving with high velocities. The basis of this served facts are not only in accord with it, but no other theory is more substantial than sheer speculation; the obadequate explanation is at hand. As the novæ have a most important bearing on the greatest of astronomic problems, and as they will presumably appear from time to time in the future as they have in the past, every resource of science will be applied to their investigation. It is well, therefore, to have sufficient understanding of the subject to appreciate the announcements of observations that will occasionally appear in the public press, which in these days is laudably eager for news from other worlds than ours.

IRREGULAR NEBULÆ

Two other general types of nebulæ require some notice—the irregular and the spiral. Both appear in immense numbers and great variety. For some reason the spirals are not found in or near the Milky Way. The cause of this is yet unknown. They abound elsewhere in the firmament to the extent of hundreds of thousands. The irregular type appear

in photographs not unlike cloud formations, with shapes as variant and fantastic, and they are generally located in or near the Milky Way. Some ragged masses show fields of condensation aglow with heat that yield the bright-line spectra of familiar elements. Others are diffused beyond conception, some being estimated at one ten-millionth of the density of air. That such gaseous clouds can be heated in the absolute cold of inter-stellar space (-273° centigrade) is impossible. Yet they give well-defined spectra, displaying the lines of nebulium, an element seldom known in any other environment. It may be that the light is of an electrical order; certainly physics and chemistry have here an unsolved problem of the first degree. It is a fair speculation that when, if ever, a more intimate knowledge of this element is obtained, a strong light will be thrown upon the cause of its presence in nascent nebular conditions.

That the nebulæ have a direct relation to stellar development is apparent from the fact that a large proportion of them contain young stars, in which nebulium is replaced by helium and hydrogen. Strikingly enough, each of these stars is usually surrounded by more or less of a hiatus, showing that the nebular matter that was near it has been absorbed. The nebulæ of the Pleiades is doubtless in the way of being taken up by that system, which presumably had its origin in centers where condensation began. Some conception of the grandeur of this spectacle may be formed from the dimensions of the cosmic field. The Pleiades are thought to be distant some two hundred light-years, and the radius of the system not less than three—six thousand times the radius of the solar system.

The origin of the vast irregular nebulæ is an absolute enigma. Since novæ have not appeared in conjunction with them, there are no concrete facts upon which to base a reliable theory of the cause. Yet the multitudes of them imply a very general cause, which seems to operate alike within and without the galactic regions. No other objects are permanent, and these may be assumed to indicate a phase

that had a beginning and must have an end, though the eons of years required for a change to be noted in any individual case renders detection hopeless, except by observing other similarly constituted objects in the initial process, should they appear. It may be that, inasmuch as the existing condition is not different from many known to be caused by novæ, these irregulars were similarly produced, but before the era of our astronomy. Examples of the irregular type resembling ragged streamers having much greater length than breadth might seem to be best explained by the action of some prodigious force, as the passage of a huge body, after a collision or disrupting approach, along a regular course at tremendous speed carrying the wreck in a long wake behind. Others, while individually spread through a vast expanse, suggest a cause not continuing beyond the scene of a catastrophe.

Without pursuing this subject further, it is evident that what is positively known is greatly exceeded by the unknown; yet it may be expected as a reasonable probability that, if current hypotheses are well founded, phenomena will eventually be observed to justify them.

SPIRAL NEBULÆ

The origin of the spiral nebulæ is not less baffling. They are known to exist in much greater numbers than the irregular; so great is the proportion that it is even thought that many of the small but apparently irregular ones are really spiral, though the type cannot be discerned because of the distance. The mystery of the spirals is such that the theory is entertained by some astronomers that they actually are not nebulæ, but remote systems of stars entirely separate from the universe to which the solar system belongs. Yet it is difficult to reconcile their appearance as revealed by numerous and excellent photographs with the idea of such stellar systems. Their arrangement and formation differ so much and exhibit so many characteristics of nebular matter

in an advanced state of condensation, that physical laws readily account for the phenomena.

They invariably have a huge central mass in spheroidal form; and in many this core is beautifully distinct and quite regular in outline. They exist in all manner of positions. Some present their entire circumference; some their lateral phases; while others show all degrees of tilt to the line of sight. Some show a high degree of concentration in the plainly evident knots or aggregations of matter scattered round about. Others display only a faint texture in the outlying parts, which are never homogeneous, but lie in strips or convolutions radiating in curved streamers from the center, like sparks from a pin-wheel. Some are right-handed, and some left, in their apparent gyrations. Few are near enough to yield clearly defined telescopic vision, yet all have continuous spectra from the knots, which demonstrates that if they are not composed of more or less solid bodies, their materials are gases in a high degree of condensation, in accord with the theory that they are stars in process of formation.

If they constitute other universes, they are unlike ours, which has no central mass; and in any event they would scarcely show rotation. On the other hand, if they are truly nebulæ, their more distinguished parts might show such motion. Thus it was announced that measurements of two plates, one taken in 1896 and the other in 1916 at the Palkowa Observatory, of one the most notable spirals (in Canum Venaticorum, M. 51) show systematic movements in thirty-six nuclei or centers of condensation; the knots in the outer spiral are receding from the central mass, while those in the eastern part of the inner spiral are moving clockwise toward the center. Similar movement has since been observed in other spirals. Recently the radial motion of the spiral nebulæ has been calculated by means of spectrograms. One is receding at the rate of 1,800 and the other 1,300 kilometers per second. The former velocity is the greatest yet known for any celestial object. These facts

would seem to upset the theory that the spirals are not a part of our universe and indicate that they are clusters in process of evolution. If they are, as generally supposed, members of our own stellar system, we are still confronted with the mystery of their origin. If produced by the collision or near approach of great bodies or clusters, novæ should result; and a considerable number have recently been noted in the spirals, but owing to their great distance they are not conspicuous. Centuries of observation may be necessary before this and other problems of origin can offer a definite promise of solution. On the other hand, phenomena may appear at any time to confirm theory or give a new turn to investigation.[2]

USES OF ASTRONOMY

Such are the outlines of cosmic evolution as now apprehended. Hypotheses, of course, in so far as they have not been demonstrated, are provisional and must accommodate themselves to new facts as they are established, or give way to new theories that will; for science is dominated by the sole purpose of arriving at the truth. Behind the facts now known and the speculations that seem most in harmony with them, lies a maze of physics and mathematics scarcely conceivable by those who are not acquainted with the methods employed in astronomy to test and verify every fact however slight and every principle however limited in its application. Every generalization is based on the accumulated data gathered by a succession of able men who have each bestowed a lifetime of aptitude and labor to some essential branch of research. Besides all this, the gradual perfection of the instruments and appliances which have been devised in aid of the study of astrophysics display an order of invention and mechanical skill unequalled in any other field. And these results have been made possible largely by the munificence of practical men who, having amassed fortunes in business enterprise, devoted ample funds to the equipment of astronomic study.

If the sublime science of the stars had no other result than to enlarge the boundaries of intellectual conceptions and to satisfy the innate desire to know how the universe is constituted, those objects would warrant the genius and labor devoted to them; but the results are material as well. Astronomy is essentially physics; and every discovery in that basic department of knowledge sooner or later leads to concrete, practical results in the domain of industrial and commercial activity with its attendant benefits to society at large.

CHAPTER II

IN THE BEGINNING

THE SOLAR SYSTEM

THE retinue of the sun being the normal product of conditions that formed the system, similar systems—varying with the masses of material and the application of the forces involved—must be attendant upon a multitude of suns scattered through the universe. But there is little hope that the probable fact can ever be demonstrated. If the present power of the telescope could be multiplied ten-thousand-fold it would not reveal planets by reflected light; indeed, if any were brilliantly incandescent, they would be too small to be seen, because of their immense distance from us. The only recourse must therefore be to theory, justified by established facts and laws of matter.

In 1894 the Lowell observatory was established at Flagstaff, Arizona, where the serenity of the atmosphere is peculiarly suited to the purpose. It was projected by Percival Lowell and directed by him until his death in 1917. He conceived the idea of devoting the work of an observatory, perfectly equipped, to the study of the solar system—"planetology," as he styled this division of research. The results of the enterprise have been worthy of the conception. Lowell is best known for his zealous advocacy of the theory that the planet Mars is an abode of life; but perhaps his most enduring merit is the great impetus he gave to popular interest in astronomic science. With a fertility of speculation, in some cases in advance of the more cautious and conservative members of his profession, he possessed in a high degree the faculty of presenting abstruse phases of astrophysics in a clear and engaging way. He thus fulfilled most admirably the scientist's function of disseminating knowl-

edge, which stands close in importance to acquiring it; for its power is in the ratio in which it is spread.[3]

It had long been apparent to thoughtful minds, not so engrossed in a single aspect or department of science as to neglect the bearing of the others, that the solution of the ultimate problems can be reached only through correlation. If evolution be universal, every phase is a link in an unbroken chain from primal matter. This is the basis of Spencer's Synthetic Philosophy, and therefore the source of the potent influence, direct and indirect, which he has exerted upon modern thought.

Lowell complained that text-books of science limped far behind the progress of knowledge, and even accused geologists of ignoring certain decisive facts that astronomy placed at their disposal. However this may be, it was reserved to Chamberlin, an American geologist, in conjunction with Moulton, an astronomer, to replace the outworn Nebular Hypothesis with a theory of the origin of the solar system more in harmony with the facts known and the operation of physical laws. This is known as the Planetesimal Hypothesis, and is more widely entertained than any other at the present time by men of science best qualified to recognize any structural weakness in the reasoning.

To understand this theory is indispensable to those who would know the most advanced opinion as to the origin of the earth and the system to which it belongs. And this knowledge involves much more than an important speculation: it requires some acquaintance not only with the physical conditions that now exist, but with the progress of physical science in recent years and the modifications it has compelled in previous theories devised in the absence of data and principles now accepted. The most elementary facts concerning the organization of the solor system are now very generally understood; but they may be usefully restated in connection with some other significant features not so commonly known.

To visualize the position of the earth and its relation to the sun a simple illustration will serve better than an array of imposing figures. Thus, if the earth were the size of an orange, and the sun and its distance were of like ratio, the sun would be a glowing globe some 25 feet in diameter, with the earth revolving around it in a nearly circular orbit about half a mile away. The most outstanding fact of the system is that all the planets revolve about the sun in the same direction and in nearly the same plane, which is called the plane of the ecliptic. This fact is conclusive evidence that the entire system was started at the same time and by the same impetus.

The diameter of Mercury, the innermost plant, is a little less than 3/8 of the earth's. Its axis is nearly perpendicular to its orbit, which is quite eccentric, but its orbital plane is much more inclined to the ecliptic than that of any of the other seven planets. The period of its revolution is 88 days. Under the immediate dominion of the sun—the mean distance being 36 million miles, a little more than 3/8 of the earth's—tidal movements long ago extinct brought its rotation to the period of its orbital revolution, precisely as with our moon; thus it always presents the same side to the sun. It has no atmosphere: the restraint of its gravitation was not great enough to prevent the dissipation of its gases.

In size and probable constitution Venus is so nearly like the earth that it would doubtless be an abode of life at an early stage but for a physical infirmity from which the earth is exempt. The year is about seven and a half months of our time—225 days. About two-thirds of our distance from the sun, the doubled power of its rays would yield a heated climate from pole to pole, the axis being nearly upright to the orbital plane. But, like Mercury, one side is probably bathed in the sun's torrid glow, and the other sheeted in perpetual ice. Too near the sun to withstand the tidal forces set up by its attraction, the initial rotation gradually merged in the orbital revolution. Great enough, like the earth, to have and to hold an ample atmosphere, the currents pro-

duced by such unequal temperature would have removed most of the evaporated moisture from the warm to the frigid side, where it would be deposited as ice. Such, at all events, are the generally accepted conclusions of the planetologists of Flagstaff, but they depend on the time of rotation, which has not yet been conclusively determined, and is still the subject of controversy.

That a planet, even so favorably situated as Venus, should not at some stage of its history be an abode of life is consistent with other orders of phenomena. There can be no phenomena that are not produced; hence they cannot be inconsistent with causes. If the origin and evolution of life are normal results of suitable conditions, those precise conditions must first exist. Whether or not a planet shall be productive of life depends not on the system to which it belongs but on its individual conditions. Nature is no doubt as regardless, so to speak, of what proportion, if any, of the members of planetary systems shall beget life as of the proportion of embryos that become adult, and may be as prodigal of one as of the other. Yet the conditions of life may be far more elastic than positive knowledge has demonstrated. These considerations apply with peculiar force to Venus on one hand and to Mars on the other.

The orbit of Mars, the outmost of the four inner planets of the solar system, is slightly ellipse, the mean distance from the sun being somewhat more than 1½ times that of the earth and the axis is slightly more inclined. The Martian day is nearly 38 minutes longer than ours, and the year about 687 of our days, therefore the seasons are nearly twice as long as ours. The diameter is a little over ½ of the earth's; the density about $7/10$; the volume about $1/7$; and the surface a little less than $1/3$, without oceans and without mountains. The mean temperature is much lower, Mars receiving from the sun only $4/9$ of the light and heat received by the earth. The atmosphere is much drier than ours. The water on the planet is supposed to be derived wholly or mainly from the seasonal melting of the polar snows, which

are plainly visible through telescopes of moderate power. The so-called canals, reported by Lowell with much circumstantial detail, are also seasonal, waxing and waning with the polar caps. The greenish hue of the Martian summer lends some support to the reasoning that the "canals" are strips of vegetation, stimulated by irrigation from the melting snows, through an elaborate system of artificial channels. Such a system would be a marvel of engineering skill and achievement, showing a high order of intellect. The supposition that such works are feasible, under the spur of necessity, is aided by the conditions that exist there. The surface gravity is only about $\frac{4}{10}$ of the earth's, so that the same exertion there as here would accomplish a proportionately greater result. The serious doubts entertained by the critics of Lowell's theories should eventually be determined: for the solution is probably within the ultimate resources of science.[4]

The four outer planets, owing mainly to their vastly greater size, are in a different condition from that of the inner four. All are largely gaseous. Their orbits are only slightly elliptical. Jupiter, the major member of the system, revolves at a mean distance from the sun of about $5\frac{1}{5}$ times that of the earth, in a period somewhat less than 12 years. The axis is but slightly inclined to the plane of the orbit. The rotation at the equator is about 9 hours and 50 minutes, while the polar zones are several minutes slower. As might be expected from such a plastic condition, the form of Jupiter is distinctly oblate. The diameter at the equator is over 88,000 miles. This immense volume implies some 1,400 times that of the earth, though the actual mass is only $314\frac{1}{2}$ times greater. The mean density is only $1\frac{1}{4}$ times the density of water. This signifies that the external volume is composed largely of heavy vapors, probably metallic, for the temperature of the interior must be very high. The planet is doubtless in the last stages of incandescence, not brilliant enough to be luminous through its murky envelope and across the vast distance that separates us, at least ex-

cept in small areas continually changing through movements from below. These characteristics account for the banded and variant appearance of its disc. Its brightness, therefore, is due to its size and its albedo or reflecting power, which is a little greater than that of fleecy clouds. In short, the chief interest in Jupiter is in the evidence it gives of the beginning of the obscurity to which all stellar bodies are eventually doomed.

In all essential features, Saturn, the next outlying planet, bears a strong resemblance to Jupiter. Its mean distance from the sun is 9½ times that of the earth, and its diameter about 9½ times greater. The axis is inclined 27 degrees to the orbital plane. The period of revolution is 29 years 167 days. The time and character of its rotation and its form are much the same as Jupiter's. The volume is about 750 times the size of the earth, though the actual mass is but 94 times greater, the mean density being about ⅛ of the earth's. Saturn is therefore composed of somewhat lighter materials than Jupiter, probably having a concentrated core and a relatively deeper envelope of gases and vapors; but, in the main, the two planets exhibit a very similar physical stage, which points strongly to unity of origin.

Uranus and Neptune show a somewhat similar kinship. Both were unknown to the ancients. Uranus was discovered as a planet in 1781. It had been seen repeatedly before, but was mistaken for a faint star. Study of Uranus led to the discovery of Neptune. The normal orbit of Uranus was soon determined; but before 1845 observers noted an increasing irregularity which could only be accounted for by the pull of an unknown body. Mathematicians soon found the probable location of the stranger, and in 1846 the telescope readily found the outmost of the planets. The distance of Uranus from the sun is about 19 times that of the earth, and that of Neptune about 30 times. The period of one is 84 years 7 days, and of the other, 164 years 284 days. As both planets shine only by reflected light little is known concerning them by direct observation. Both are markedly

spheroidal; hence they are in a highly diffused state and in rapid rotation. The diameter of Uranus is somewhat less than four times the diameter of the earth; the volume about 65 times; and the mass about 15 times. In density it is of much the same order as Jupiter. "Without even an embryo core," says Lowell, "its substance passes from viscosity to cloud." There is no great difference in size or general character between it and Neptune. Both are aggregations of gases and vapors rather than solid materials, and doubtless contain a much lower percentage of the heavy elements of the interior planets. Uranus has a greenish hue, caused by the absorption of other rays by some peculiarity of its extraordinary atmosphere. Indeed, the spectrum contains certain dark bands possibly produced by one or more elements not known elsewhere. Another distinguishing fact which may have an important bearing upon the question as to the origin of Uranus and Neptune is the character of their rotation. Uranus is inclined about 98 degrees and Neptune about 145 degrees to the plane of the ecliptic. This means that their rotation is retrograde—from east to west, unlike that of all the other planets, though their orbital revolution is from west to east like the others.

The satellites of the solar system are probably a miniature application of the physical laws that governed the formation of the system itself. Mercury and Venus are moonless. Presumably they were too near the sun to hold moons in revolution about them. Our moon, proportionately to the size of the earth, is much the largest attendant upon any of the planets, and is actually larger than most of them. This anomaly has led to the opinion that originally the earth and the moon were one, separating while in a plastic state through rapidity of rotation, after the manner of binary stars. The diameter of the moon is a little more than $\frac{1}{4}$ of the earth's, and its mass about $\frac{1}{80}$. Its orbit, like that of most satellites, is quite eccentric, the mean distance from the earth being 238,862 miles. Like Mercury and Venus, and like all the satellites so far as fact can be determined, the

revolution and rotation of the moon are the same. Its surface is relatively much rougher than the earth's, many of its elevations being as high as the earth's highest and some even higher. It is scored and pitted by craters great and small, apparently the result of by-gone volcanic activity, though the cause is uncertain. This feature is one of the evidences that the moon was a part of the earth's primordial bulk, as otherwise it would not have had the heat to produce such convulsions. But the effects of the eruptions have remained unchanged. Too small to hold an atmosphere, the primeval roughness of the surface has not been worn and eroded by the action of air and water. There it wheels its silent course, the fragment of a world in which even the chemical forces of matter are wholly inert. And thus it will continue until perchance some new cataclysm shall awaken its dormant energies and distribute its elements into other forms with different destiny.

Mars has two moons more diminutive than their names would imply. Phobos (Panic) is probably somewhat less than 30 miles in diameter, revolving in 30 hours and 18 minutes in an orbit nearly 4,000 miles from the planet. Deimos (Fear) is not more than 10 miles in diameter, revolving 7 hours and 39 minutes at a distance of about 12,500 miles. Both are barely large enough for gravity to mould them into spheres; and such is the perfect balance of gravitational forces that when Mars drew them from the welter of the beginning, their speed preserved their existance at the price of their freedom, the paramount law alike of planets and of moons.

Jupiter and Saturn have each a large known retinue, and probably a still larger not yet known and possibly not discoverable because of their smallness and distance from us. These satellites are in themselves almost a demonstration of the catastrophic origin of the solar system. The great size of Jupiter and Saturn, their distance apart and from the other planets would necessarily endow them with the attractive power to draw a swarm of minor bodies, dispersed ma-

terial, either into themselves or within their orbital jurisdiction as satellites. Four of Jupiter's moons were among the first objects Galileo beheld with his primitive telescope. The ninth was found in 1914 upon a photographic plate, being otherwise invisible. Two of these moons are over 3,000 miles in diameter.

Saturn, like Jupiter, has nine known moons, one of them being about the size of Jupiter's largest. The rings of Saturn, the most spectacular feature of the planet, are merely several concentric bands of loose material—very small bodies or particles of matter—revolving at different speeds and held in their scattered positions by the counter attraction of the planet and the moons. The rings are about 172,600 miles in diameter, more than twice that of the planet, but they are not over 40 miles in thickness, which is neither regular nor constant. Like most of the moons, the rings revolve in the equatorial plane.

It is a fact not to be neglected that the two outer moons of Jupiter and the outermost one of Saturn are retrograde, revolving from east to west. From this the inference is drawn that the original motion of the planets was reverse, having been compelled by the pull of the sun to conform to its rotation. The inner moons have obeyed the mandate; but the outer ones, under less compulsion, have lagged behind as the greater inclination of their orbits indicate. And this inference is aided by the conduct of Uranus and Neptune. The former has four known satellites, and the latter one. Doubtless there are others which are invisible. The five revolve in the equatorial planes of the planets and are therefore retrograde.

Between the orbits of Mars and Jupiter is an expanse of about 342 million miles long supposed to be untenanted, but now known to be the course over which the planetoids pursue their chase around the sun. They range in size from masses 500 miles in diameter to the point of disappearance. Their paths are generally far more eccentric than the planetary orbits, and some of them display an equal disre-

gard of the plane of the ecliptic. Three of them intrude within the orbit of Mars and one, Eros, periodically comes nearer to the earth than any other body except the moon. On the other hand, four pass beyond the orbit of Jupiter. However, they all revolve from west to east and rotate likewise. The smaller ones resemble gigantic boulders torn from their surroundings and are too small to be drawn into spherical form.

It is not to be doubted that besides the few hundreds catalogued, there are myriads of others too small to be seen, like the debris of some vast catastrophe, strewn through the space in which they circle. Their somewhat erratic movements are due to their smallness and the diverse attractions to which they are subject. The conditions resemble those which hold the components of Saturn's rings from combining into one or more aggregations of satellite size. Yet if all the planetoids known were merged into a single body, it would not much exceed $1/40$ of the moon's mass.

Comets, having lost the terror they formerly inspired, have gradually assumed their true character as minor astronomic phenomena. Positive information concerning them is still limited; but enough is known to afford an explanation of their origin, nature and conduct. Certainly the great majority are as native to the solar system as any of its members. While it is possible that some of them may have been picked up by the system during its long passage through space, the evidence proves that most of them have not. Although in many instances they deviate from the plane of the ecliptic and are retrograde, they often observe the direct sense of the system. The latter tendency is explained by the tenuous composition of comets and the ease with which their motion may be deflected by too near approach to the great exterior planets. Indeed, Jupiter has caught and permanently held within its jurisdiction some three dozen of them; and the other outer planets have made similar captures. This accounts for their short periods. They round the sun, but in

each instance the outer end of the ellipse is just beyond the orbit of the planet that has influenced it.

There are probably great numbers of comets ordinarily too small to be visible. Such have been seen during eclipses of the sun. Those which have not been captured by planets travel in enormously elongated courses, some having periods of several hundred years; a few may not belong to the system, but have been overtaken by it. Their composition is not uniform, yet they contain no unfamiliar elements, as shown by their various spectra. When remote from the sun their form is loosely spherical—an interior nucleus containing more or less solid or condensed material, small bodies or particles surrounded by a gaseous envelope. As they approach and pass around the sun the outer gaseous part, which is rarified and diffused in an extreme degree and may contain matter in a state of impalpable division, is driven away from the sun by the pressure of its potent light and electrical repulsion. These emanations comprise the tail, the form depending on the nature of the material. During this process the head contracts and the tail increases. Then the order is reversed until the objects resume their former condition except when disrupted by the pull of the sun. The last great comet appeared in September, 1882, and is still a vivid memory to those who witnessed it. For a time its head was about 150,000 miles across, and its tail more than 100 million miles in length. While typical of comets generally, it was smaller than some recorded before the nature of the apparitions was understood.

The chief significance of comets lies in the fact that they are probably the odds and ends of the cosmic mass in which the solar system had its origin. In the outlying reaches of the system, far beyond the orbit of Neptune, there may yet be remnants of nebulous matter from which new comets are recruited; for it is well established that great comets of the past have been broken up and dispersed during their successive journeys around the sun. It is likewise known that meteor streams through which the earth periodically passes

are in the tracks of extinct comets, the meteors themselves, in all probability, being the components of the once brilliant visitants that appalled the credulous inhabitants of the earth.[5]

Presumably several millions of small meteors are caught and consumed in the atmosphere every day. Only the greater ones, which are relatively few, have survived the friction of their rapid passage through the air. The largest known is the Cape York nickel-iron meteorite brought from Greenland by Peary in 1895, weighing 36½ tons, now in the Museum of Natural History in New York City. Specimens of the many varieties have been analyzed, and some thirty of the elements, in many combinations, have been found in them. The composition and structure of these fragments and the gases occluded in them are such that they must have been incorporated in a great body or bodies afterwards shattered by powerful forces; otherwise the heat and pressure necessary to form the concrete masses of which they were a part could not have been produced.[6]

Allied with the comets and the meteors are the zodiacal light, the aurora and the peculiar characteristics of the daylight. Extending from the sun to a great distance beyond the earth's orbit, how much further is unknown, is a diaphanous mist, so to speak, produced by minute particles of matter. They may, for the most part, be mere atoms or molecules so small as to defy the microscope. The zodiacal light is a ghostly wedge-shaped reflection from the sun after twilight and likewise in the east before sunrise when the seasons and atmospheric conditions are favorable. Seen in the clear skies from the mountain-tops it stretches in a faint band around the ecliptic. Another similar illumination, oval in form, known as the gegenschein, is also sometimes observed in the sky on the ecliptic opposite the sun.

This thinly diffused matter is symmetrical in its extension, but wider along the ecliptic than deep through the poles. No doubt the aurora is caused by the magnetic energy of the sun acting upon this discrete substance. Without

it the sky would be dark at noonday, and the shadows sharp and deep. Aided by the molecules of the atmosphere, it scatters the direct rays of the sun, diffusing the glare into a softer and more general glow. In the upper regions of the air the particles are so small that they reflect only the shorter wave-lengths, thus illuminating the sky and tempering the color to blue. As the larger particles are nearer the earth their reflection of the longer wave-lengths of the spectrum yield the gorgeous tints of sunrise and sunset. Even the precipitation of rain, as we know it, would be impossible but for the agency of this impalpable dust in starting the condensation of the moisture in the clouds; yet the very minuteness of the particles soon restores them to the altitudes from which they are carried by the raindrops, through causes somewhat analogous to those which develop the comets' tails.

The total mass of this matter is very considerable. The motion of Mercury at perihelion is faster than required by known forces. The other planets and the moon show perturbations difficult to account for. This movement of Mercury was formerly ascribed to an interior planet. When it was determined that there is no such body, the cause of the anomaly was sought in the gravitational effect of the total mass of the cosmic dust, assuming it to be approximately equal to that of Mercury. The true explanation is now asserted by the theory of Relativity.[7] However this may be, we may fairly infer that the diffuse material is due to the same cause that brought the solar system into being and is therefore a normal incident of planetary organization.

THE SUN

No feature of astronomic study has been the subject of such varied and profound interest as the sun. Not only the center of the system, the gravitational power that holds the planets in their courses, it is the source of every function that begets and supports life on the earth. Without the energies sustained by its light and heat, the varied conditions

upon which they react, whatever may be their other potentialities, would be barren of biological results. A star among stars, the fellow of myriads, it measurably supplies the details that all the perfection and refinements of astrophysical research cannot bring from the distant orbs. Readily amenable to the resources of scientific investigation, it has richly rewarded the labors of science. Knowledge of its character, components and conditions has rapidly increased from year to year, until in most respects its tremendous phenomena are understood as intimately as any objects of laboratory study. For the present purpose the essential features may be sketched with a brevity that gives slight token of the manifold physical researches by which the data have been developed.

The first fact that arrests attention is the magnitude of the sun as compared with the other elements of the system, though much smaller than many other stars of the same type. In constitutes 99$\frac{6}{7}$ per cent. of the total mass. Thus all the planets, satellites and other matter in the system outside of the sun form but $\frac{1}{745}$ of the whole. This fact is of prime significance in any speculation as to the origin of the earth.

In volume the sun is more than a million and a quarter times larger than the earth; but as its mean density is only 1.41 as compared with water, the mass is about 333,000 times greater than the earth. It inclines about 7 degrees to the plane of the ecliptic. As may be implied from its physical character, its form is slightly oblate. The rotation at the equator—24.6 days—is more rapid than that of the parts toward the poles. The materials and condition of the interior are unknown except by inference, but the deductions may be regarded as reliable. By no possibility can any part of this huge body be composed of solid matter. The surface temperature is some 6,000 degrees centigrade. The far interior is of necessity vastly hotter. In the presence of such heat, enormously surpassing the highest degree that can be produced in an electric furnace, the materials must be in a

gaseous state—compressed, indeed, into a condition resembling liquid, but still possessing the indefinite expansibility of gases.

Most of the chemical elements are distinctly present in the sun, and it is probable that all exist there, actually or potentially. The number identified has steadily increased in recent years, and the few remaining undiscovered may well exist in the interior regions where they would naturally assemble because of their uniformly heavier atomic weights, if all are yet evolved.

The paramount fact of present interest is the immense heat of the entire body, which largely accounts for the varied phenomena it exhibits; and this condition points to an origin in cosmic forces on a grand scale.

The radiating surface, the photosphere, presents a granulated appearance, commonly known as the "rice-grain structure," these mottled granulations, however, being several hundred miles in diameter. Their peculiar aspect is probably due to their uneven heat and radiance. Dark patches, the "sun spots," variable in number and location, but never at the equator or near the poles, are usually present, traveling across the disc with the rotation of the sun. The spots are surrounded by "faculæ," ragged patches more vividly bright than the surroundings. The prodigious volume of diffuse gases that envelop the more concentrated mass is shown by the greater brilliance of the middle of the disc; a photographic plate well exposed at the center is weak at the limb or outer rim of the disc. The same cause produces the sharply defined limb: we look obliquely through a much greater depth of gases toward the rim than at the center. We lose the rays from yellow to violet by scattering and absorption. Notwithstanding this partial blanketing of the radiant photosphere, it has been estimated that each square inch of surface emits as much light as 25 electric arcs. By experiment it has been found that the sun is 5,300 times brighter and 87 times hotter than the white-hot metal in a Bessemer converter. This intense heat and

brilliance is supposed to be caused mostly by repeated radiation rather than by vertical convection currents.

Covering the entire photosphere is a relatively thin stratum of gases, to which incandescent hydrogen gives a scarlet hue. This is seen as a ring around the limb during an eclipse, and is therefore termed the chromosphere. From its irregular outline and numerous jet-like prominences it is evidently at all times in a state of violent agitation. They usually leap to a height of 5,000 or 6,000 miles, but often mount to 100,000 miles and sometimes much higher, assuming many different forms, because of the nature of the gases composing them and the velocity with which they are projected from the seething mass below. This velocity is sometimes as high as 300 miles per second. While the displays are not dependent upon the sun spots, they are violent and extensive in connection with them. Between the photosphere and the chromosphere is a very thin stratum of somewhat less heated gases, known as the "reversing layer," owing to the effect it has upon the spectrum. Outside of all this is the corona, a tenuous pearl-hued envelope, visible only during a total eclipse of the sun. This appears to be more uniform in its extension when the sun-spots are at their maxima; at other times it is very irregular in its manifestations. Comets pass through it without apparent obstruction or commotion. Whether purely gaseous or partly meteoric dust, its texture must be extremely diffuse. Its luminescence is probably electrical, like the aurora, and reflected light from the sun rather than incandescence.

A sketch of the sun cannot well omit some detailed notice of the spots, which may eventually prove an important factor in meteorology, the science of the weather. A spot consists of a dark interior, the umbra, surrounded by a less dark fringe, the penumbra. Being less brilliant than the main surface of the photosphere, the spots appear dark by contrast. They are of varied extent, the larger ones often having a diameter of 40,000 miles or more. They may appear singly, but generally in groups, as one or more large spots together

with several smaller ones, all having the same characteristics. They are unstable in size and duration—appearing quite suddenly, rapidly expanding to their maxima, then contracting until they vanish, absorbed by the photosphere. Their average duration is from two to three months; but this is subject to many exceptions. Spots may come and go in the course of a day; some have lasted a year or more. They may combine and divide, disappear and immediately reappear. The most fixed and definite characteristic is the regular cycle of their smallest and greatest number. This period covers about 11¼ years though varying from 7 to 16. The interval from minimum to maximum is invariably less than the reverse. That the maxima are attended by certain terrestrial phenomena is now well established. The auroral displays are then the greatest; changes in the earth's magnetic field are the most marked; and the prevailing temperature is lower. It is quite significant that the extent of the polar caps of Mars is amenable to the same alternations of the sun's mean temperature. Thus the statistics of future observation may lay the foundation for principles of meteorology of practical service in the affairs of the world.

According to the prevailing opinion of the ablest students of solar phenomena, the cause and development of the spots are proximately due to local changes of temperature, followed by the normal physical and chemical action of the matter involved. The faculæ are highly heated areas, presumably produced by the accumulation over them of gaseous matter, prominences of the chromosphere or greater density of the corona, that somewhat impedes their radiation. The resultant heat causes expansion below; and the reduced pressure causes the formation of vortices, which probably take a shape and motion similar to that of water-spouts at sea. As the matter rises the tendency would be to impel rotation, the movement being in the form of a spiral from within outward. As the flux approaches the limb the temperature lowers by the expansion of the mass. The outer center of the vortex would tend to produce a vacuum draw-

ing in the high-level hydrogen of the chromosphere and its prominences. As the equilibrium is restored the spots contract and disappear. They are invariably the centers of powerful magnetic fields. The vortices apparently operate as huge dynamos. In rapid rotation the friction of dissimilar materials and other physical causes are supposed to give rise to great charges of electricity. On reaching the surface these currents manifest themselves in the magnetic effects conspicuously incident to the maxima of sun-spot activity.[8]

These conclusions are the gradual results of long and profound investigation; and for the most part they are logical deductions from a multitude of separate facts revealed by the spectroscope. Much, of course, remains to be learned, particularly the cause of the periodical changes, the nature of the corona and the areas of the faculæ. But that all will ultimately yield their secrets may be reasonably expected. They are unquestionably the normal phases of stellar history. The fact is highly significant that the spectra of the sun-spots are almost identical with those of the old red stars.

Such are the external aspects of this great body. The difficult problem of the duration and stability of its existing energies will be most profitably considered in their relation to life, past and present, after some review of the constitution and conduct of matter. With this survey of the principal facts concerning the solar system, it now remains to present the explanation of its origin according to the Planetesimal Hypothesis.

THE FAILURE OF THE NEBULAR HYPOTHESIS

The definite conception that the solar system is the product of evolution apparently originated with Kant, the philosopher, when he was a young man. So early as 1755, when the idea of evolution in any phase of nature was revolutionary and abhorrent, he sought the origin of the sun and its system in the condensation of elemental matter in a cold and diffused condition, the sun around a central nucleus and the

planets and moons around outlying and smaller centers. His ideas, however, were valid only as a loose generalization. Yet it was half a century before Herschel's remarkable studies of the nebulæ and long before some of the most important dynamical laws were discovered, even before the atomic theory of chemistry was conceived. He assumed that an initial mass of gaseous matter at rest would of itself, without external force, develop rotation; this is now known to be impossible. Some years later, after the announcement of the principle that heat is produced by the compression of gases, he attributed the heat of the sun to its gradual condensation, a process that must eventually come to an end, as already demonstrated by the planets. About a century afterward, the theory was established by Helmholtz and is now accepted as a fundamental truth, with the addition in recent years that the process is extended by the dissolution of radioactive substances. Kant also maintained that tidal effects would retard rotation and finally bring the planets to the status of the moon, continually presenting the same face to the center of the gravitational force. "I seek," said he, "to evolve the present state of the universe from the simplest conditions of nature by means of mechanical laws alone." His conceptions were magnificent and far in advance of his time. It has been the function of science in this as in other cases of brilliant generalization, which have usually been little more than shrewd guesses, to find the flaws and discover the true mechanism by which the ultimate results were accomplished.

In 1796, Laplace published a popular work on astronomy, which had a long vogue, due to his eminence in that branch of science. In the last of a series of notes at the end of the volume he proposed the explanation ever since known as the Nebular Hypothesis to account for the origin of the solar system. He was unaware of Kant's writings on the subject, and was doubtless prompted by Herschel's discoveries in relation to the nebulæ. There is no reason to suppose that he considered his idea as very important; indeed,

he remarked that it should be received "with the distrust with which everything should be regarded that is not the result of observation and calculation."

The hypothesis was that the solar system had evolved from a nebula of heated gases extending beyond the present orbit of the outmost planet, the whole mass being in slow rotation at an angular rate, like a revolving solid. The mass was in equilibrium through the expanding forces of heat and rotation and the contracting force of gravitation. As the heat was reduced by radiation the size diminished and the speed increased. The speed at length became so great as to disengage an outer ring, which retained its equilibrium, continuing to rotate as a solid, while the main mass contracted. By the repetition of this process ring after ring was thrown off until only a central body was left. The nebulosity of the rings not being uniformly distributed, broke into fragments, all the parts of each ring eventually coming together as one mass. These several masses, except those forming Venus and Mercury, in turn repeated the process, thus developing the satellites, save only in the case of Saturn, whose rings for some reason did not coalesce, but arranged themselves as solid matter instead of a moon or moons.

Such was the extraordinary hypothesis that for a century commanded unquestioned acceptance. Laplace, like Kant, was impressed by the assumption that all the satellites revolve around the planets from west to east nearly in the common plane of the solar system. He was apparently unaware that Herschel had announced that the two recently discovered moons of Uranus were exceptions to the rule. This was the first shock to the Nebular Hypothesis, which became a fatality by the irreconcilable fact that not only eight moons, but two of the planets themselves, are practically retrograde.

Other elements of the problem proved as refractory. If the materials of the system originally existed as gases distributed uniformly they would have been several hundred

million times more rarified than the air we breathe. With such a condition the abandonment of successive rings to form the planets and the planetoids would have been impossible. But if such rings could have been formed the inner parts would have moved faster than the outer ones; thus the rotation of the planets when finally formed would of necessity be retrograde. Such a ring could not rotate as a solid; physical laws require that each constituent of such a gaseous ring move independently of other particles. If the inner ring of Saturn were produced according to the Nebular Hypothesis, the period of its revolution would be greater than that of the planet: it is only about one-half. The same principle would apply to the inner moon of Mars: its period is only about one-third of the planet's rotation. The theory would also require that the planetary orbits be nearly circular: they are all eccentric, particularly that of Mercury which should be nearest to a perfect circle. Not less inconsistent is the inclination of the sun to the plane of the system: if the theory were valid, the axis should be perpendicular to the plane.

Of all the objections to the Hypothesis, perhaps the most conspicuous is its flagrant violations of one of the imperious laws of celestial mechanics, the conservation of the moment of momentum, as it is technically and imposingly styled. "Momentum," says Lowell, "is the quantity of motion in a body. It is the speed into the number of particles or the mass. Moment of momentum denotes the rotary power of it around an axis. It can neither be diminished nor increased. It is the one unalterable thing in a universe of change. What it was in the beginning of a system, that it forever remains. By mutual action of the particles on one another, by contraction, by tidal pulls, and so on, some energy of motion is constantly being changed into heat and then dissipated away. Energy of motion, therefore, is slowly being lost to the system, and the only stable state for the bodies composing it is when the energy of motion has decreased to the minimum consistent with the moment of

momentum. Our whole system is evolving in such a way as to lessen its energy of motion while keeping its quantity of motion unchanged."

Considering the relative mass of the sun as compared with the remaining matter in the system—over 99 per cent.—fully 96 per cent. must have been condensed in the nucleus at the outset. The orbital velocity of Mercury is about 45 kilometers per second, hence the sun's equatorial velocity should now be at least 400 kilometers per second, in order to satisfy the constancy of the moment of momentum: it is only 2. Other discrepancies might be stated; but these suffice. The data of the solar system and the infirmities of the Nebular Hypothesis thus afford very tangible indications of the character of the forces requisite to produce the system as it is.

THE PLANETESIMAL HYPOTHESIS

Late in the eighteenth century, Buffon, the versatile French naturalist, suggested that the solar system was the result of a huge comet colliding with the sun. Like most of his theories, this comes well within Spencer's observation that error is generally the "adumbration of a truth." Its chief merit was that it was too heretical for consideration at that period. Later on it was discarded into the limbo of physical impossibilities. The germ of the idea long afterward took the form of stellar collision. This conception proved more fertile. At first the results were little more than bizarre guesses; but when at length the perfection of the photographic dry-plate, in 1886, began to reveal the features of the spiral nebulæ, the idea gradually acquired a more strictly scientific basis.

Astronomers have ever been conservative. The essential nicety of their calculations and the necessity for the utmost precision in all their work naturally beget a cautious and deliberate temper of mind that views most theories with rather obstinate suspicion, demanding very cogent demonstration. It is easier to jump to the conclusion that the

spirals are produced by the impact or pull of stellar masses than it is to account for the collisions and the magnitude of the phenomena. It is obvious that the great variety of nebular forms, if caused in some such manner, might be due to the many angles of approach by the colliding bodies and the degree of the impact; or, if not actual collisions, to the infinite degrees of possible proximity to one another. The subject is again referred to because of its immediate bearing on the hypothesis Chamberlin first proposed in 1901, and later, with the aid of Moulton, brought to its present form. However, the hypothesis is necessarily a special one to fit the organization of the solar system, which is a small affair as compared with thousands of the spiral nebulæ.

The earlier theories started with the convenient existence of a medium without effort to explain how it might have been brought to a condition suitable for evolution. The Planetesimal Hypothesis, on the other hand, accounts for the medium as well as the evolution, as successive stages through the operation of normal physical laws and in a manner largely acceptable to astronomic science. It assumes the sun to have been a body somewhat greater than at present and in a more diffuse state—a much younger star. At the critical juncture another body approached it in a path lying at the same angle as the plane of the ecliptic, which was thus established. When the approach was near enough a disruptive pull began. The effect of such a sudden and powerful disturbance is supposed to have been similar to the internal expulsions now witnessed at the sun's limb, but on a vastly greater scale owing to the external attraction. When the first great bolt shot outward, the immense tide it occasioned resulted in a similar ejection from the opposite side. This rapid alternation of projectiles continued during the short time the two bodies were within effective distance of one another. The matter thus drawn from the sun was given sufficient momentum to hold it from falling back upon the sun and thus arranged

itself into a variable form similar to that of a typical spiral nebula.

As to the character of the intruder even conjecture is silent. It might have been larger or smaller than the sun, and its rate of speed faster or slower. Certainly the result of the encounter might have been worse. As it was, the other body apparently made precisely the right approach in proportion to its mass to enable the sun to yield up enough of its surplus to furnish forth its retinue. With a very slight difference in the circumstances the subject would not now be under discussion.

The sequel is full of intricate detail, elaborated with painstaking attention to the principles of physics and calculations of mathematics. The salient aspects will answer here. The greater part of the resulting nebula was at first contained in knots or nuclei, which continued gaseous, but from their ampler mass were better able to retain their original heat. Of these the larger became nascent planets, and the smaller their satellites. Distributed throughout the entire system was the remaining matter in a more or less dispersed and finely divided state. All revolved about the sun in markedly eccentric orbits. The larger masses gradually gathered into themselves the adjacent matter existing in bodies too small and therefore without the momentum to resist gravitation. The combined effect of this would have been to average their orbits. This caused the paths of the planets gradually to assume their more circular form. The principle is well illustrated by the variety of eccentricity displayed by the orbits of planetoids.

The chief credentials of the hypothesis are its satisfactory explanation of the general sense of the system, the formation and motion of the satellites, and the unfailing deference to the constancy of the moment of momentum. There are, indeed, some irregularities and apparent anomalies not yet explained, but the hypothesis is so flexible that additions or modifications through new discoveries and deductions do not seem likely to impair its general validity.

One difficulty is the peculiar distribution of the masses of the planets. Lowell pointed out the suggestive fact that the arrangement of the moons of Jupiter and Saturn is analogous. This tends to show an underlying cause that applies to all such cases. The four outer planets contain 225 times as much matter as the four interior ones and the planetoids combined. But they are composed of much lighter materials than the inner ones; hence the inference that they were derived from the exterior and lighter parts of the sun's mass, the smaller and denser planets being drawn from the heavier materials within.

Another difficulty that awaits solution is the diverse inclinations of the axes of the planets to the plane of the system. It is remarkable, though entirely possible, that the disturbing body should have approached the sun at so small an angle to its equatorial plane, as indicated by the sun's inclination of only 7 degrees; for it is not probable that a force only strong enough to dislodge less than one per cent. of the sun's mass could have seriously affected its axial position. The variety of the planetary tilts increase the perplexity, but without placing the hypothesis in jeopardy. The differences in orbital eccentricity may be fairly attributed to the varied distribution of the materials that entered into the formation of the planets and the circumstances that governed the final result.

The fact that the equatorial region of the sun rotates faster than the other latitudes is ascribed to the falling back of material lifted out for a short distance, thus causing a forward tide that gave a powerful impetus to the contiguous belt. While this is regarded as possible, precisely the same conditions are observed in Jupiter and Saturn, and are therefore supposed to be due to a common cause. "The most plausible explanation of this curious phenomenon," says Campbell, "is that great quantities of materials originally revolving around the sun and each of the planets have gradually been drawn into these bodies, by preference into their equatorial areas, such masses of mat-

ter moving in orbits very close to those bodies must have traveled with speeds vastly higher than the surface speeds of the bodies." This suggestion, if valid, would seem to militate strongly in favor of the Planetesimal Hypothesis. Recently the theory has been proposed that the phenomenon is due to convection currents. This explanation applies to all bodies in which such currents are possible; and it also accounts for the belts around Jupiter and the confinement of the sun-spots to the equatorial region.

The origin of the comets is left a baffling enigma, though the attempt is made to explain it on the theory that splashes of the original matter were driven away at diverse angles to the plane of the primordial nebula.

THE JUVENILE EARTH

The astronomic phases of the hypothesis, while fundamental, are but preliminary to its practical bearing on geologic history before the Archeozoic Era. It is estimated that the amount of nebulous matter originally in the nuclei was from one-third to one-fourth of the whole. Thus the earth at the outset was some 30 or 40 per cent. of its present size. It would not have been possible for so small a body to retain heat enough to keep it in a molten condition for a very long period. That it is not so now, despite the high degree of heat produced by pressure, is generally accepted for several reasons deemed conclusive. With this beginning, the planet began to grow by attracting to itself the planetesimals—small bodies or particles, into which the primal matter was resolved. At this stage, while such matter was abundant, the growth proceeded relatively fast and continued until the infall largely depleted the resources, though a negligible residue is yet seen in the meteors on every clear night. The other planets, of course, were enlarged in the same way, and the entire system steadily approached a stable organization.

Such was the foundation of the lithosphere. Concurrently with it, the hydrosphere and the atmosphere were

built up in the same way. The gases composing them were distributed through the constituent matter and were collected along with the other elements and combinations entering into the accretion until likewise the supply was exhausted. Thus the seas were a gradual accumulation, first pouring into the oceanic basins and gradually rising until they nearly enveloped the globe. Ere long external disturbance through internal shrinkage and readjustment set in; volcanic action began its transformations; and the great triumvirate of natural processes in ceaseless interaction were at work in preparing the tenantless earth as an abode of life.

This is quite unlike the picture usually sketched under the influence of those conceptions of the beginning which had hitherto prevailed and are still general: a globe once molten, but cooled enough to allow the steaming oceans to form, dimming the sun with their dense vapors, bringing forth its sightless creatures and leafless vegetation during an eon of twilight, without change of seasons or variety of scene—a world of misty gloom and cheerless monotony.

The existing physical condition of the earth must necessarily guide any speculation as to the manner of its formation. The normal density of iron is 7.8, on the scale of water. The average density of rock formation is about 2.8. If these were combined half and half the result would be 5.3. The mean density of the earth being 5.5, it is a fair inference that the chief ingredient of the interior structure is iron, which is known to exist in abundance very generally in stellar bodies, throughout the universe. If the exterior of the earth were a shell enclosing a molten core, the tidal effects would be prodigious in the shell itself. On the other hand, if the entire earth were absolutely rigid, the tides of the ocean would be much greater than they are. The fact is that the globe is elastic without distortion; it yields, but at once regains its normal form. It responds precisely as though its rigidity were somewhat greater than that of solid steel. Again: there is an oscillation of latitude of

points on the earth's surface. These variations pass through their principal cycle in a period of 427 days, the entire earth oscillating slightly during this time. If the earth were absolutely rigid, the period would be 305 days; if exactly as rigid as steel, 441 days. Thus the results are in practical accord.

The distribution of the more external materials of the globe is far from uniform in density. This is shown in several ways. The magnetic poles are quite distant from the poles of rotation, and they are not directly opposite to one another. Likewise the lines of equal magnetic intensity are very irregular over the earth's surface. Deflection in the direction of the plumb-line and changes in the force of gravity also indicate that the outer strata are of unequal density down to a depth of 122 kilometers. Below that level the density of concentric regions appears to be quite uniform. The first waves from a distant earthquake come directly through the earth, and the speed is greater directly through the center. The change of speed is gradual from the center outward, showing that the density is greatest at the core.

All the evidence shows that, while the earth is now entirely solid or acts as such, it was not always so. When the nucleus was in more or less molten state the denser materials gravitated toward the center and therefore developed a more homogeneous character. The internal heat, now due wholly to pressure, increases at the rate of 1° centigrade for every 30 meters. If this rate is maintained, the heat at a depth of sixty kilometers would be sufficient to melt platinum, the most refractory of known metals; but fusibility decreases with pressure. Thus at a great depth the materials could not melt, though they would instantly liquify if the pressure were removed.

Such data tend strongly to confirm the Planetesimal Hypothesis. The outer regions of the globe during geologic time were never in a molten condition, except where they have been affected by volcanic action. The accretions were

not of that character, nor were they of uniform composition. This accounts in part for their varied density and the diversity of the materials. The same general cause is held to explain the characteristic difference between the northern and southern hemispheres. Much the greater part of the continental areas lie to the north and are therefore supposed to consist of somewhat lighter materials. The existing land of the Antarctic is of a later geological development, and doubtless exerts a decisive influence upon present climatic conditions by obstructing or diverting the main oceanic currents.

An important feature of the hypothesis is its explanation of the continental formations. The exposition of the process is one of the most admirable stages of the entire argument and has met with very general acceptance by geologists. It is essentially one of dynamics. Only a few of the leading considerations may be referred to here. The original rate of the earth's rotation was probably much higher than during purely geologic time, oscillating until the growth of the planet was substantially complete and equilibrium was obtained. This would have caused stress and strain. When the rotation slackened, the equatorial tract would tend to sink and be compressed, while the polar parts would rise and suffer tension. Between the rising and falling tracts lay fulcrum zones, not far from 30 degrees North and South Latitude, which would neither rise nor fall. It is assumed that a sort of segmentation would follow along the most natural lines. This would roughly divide the circumpolar areas into three great centers of triangular form starting from the poles and resting on the fulcrum zones. The weak and strong segments would assume antipodal positions. The heavy and rigid sub-oceanic cones would stand opposite the lighter and yielding continents with an area of about two to one. And this is precisely what happened. The embossment of North America is opposite the basin of the Indian Ocean; of Australia, opposite the basin of the North Atlantic; of Africa, opposite the Central Pacific; of South Amer-

ica, opposite the western extension of the North Pacific; and so on. Thus the three great oceanic abysses appear not only to have crowded aside the continental masses, but to have joined in thrusting toward the earth's center.

It should be remarked that this work was accomplished during the juvenile history of the globe. If the rotation had slackened during geologic time the equatorial region would have crumpled and the polar areas stretched. This would have raised mountains in the torrid zone and leveled the higher latitudes. Such differential effects do not exist; hence it is to be inferred that sensible changes of that nature have not occurred during the entire stage of normal geologic transformations.

Long before the general alignment of the continental platforms was determined and during the later phase of planetesimal accretion volcanic agencies began their work, the radio-active elements probably being a leading factor. The readjustment of the mixed materials of the mass tended to press outward the lighter ingredients in much greater proportions than the metals and metallic alloys. In this manner the heavier matter would gravitate toward the interior, which became more and more rigid while the crust became more amenable to movement and transformation. "The inner reorganization of the juvenile earth," says Chamberlin, "is therefore pictured as a process that affected pervasively the whole interior of the earth, preserving effectively the solid state of the main mass and progressively increasing its average rigidity, while at the same time it set free and forced toward the surface, stage by stage, the lighter and more mobile material. The mixed states of the meteorites, our best guide in the matter, do not encourage the notion of complete segregation."[9]

Such are the outlines of the Planetesimal Hypothesis. Geology had reached the uttermost limit of its researches and had scarcely arrived at the horizon of primordial life. The Nebular Hypothesis had collapsed, and the vast chasm between the earth's origin and the condition to beget life

remain unbridged. The need for explanation was urgent, and the progress of physical science had supplied the means. The result was worthy of the diversified knowledge and profound deductions that achieved it. That the structure is finished and invulnerable is far from certain. It is not unlikely that the theory will undergo modification and amendment of detail, especially as to the inception of the system, through the long process of searching analysis to which it will be subjected in the light of advancing knowledge; but, if fundamentally sound, as it now appears to be, its essential flexibility would bear any strain that may be placed upon it. In any event, acquaintance with the process of evolution, it portrays, is indispensable to every mind that would grasp the foremost thought of the age.

CHAPTER III

THE GEOLOGIC RECORD

PROCESSES

THE diameter of the earth at the equator is 7,926.57 miles, nearly 27 miles greater than the diameter through the poles, the difference being caused by the centrifugal force of the daily spin. One-half of the total volume of the atmosphere lies within an altitude of 3½ miles. In an increasingly rarified state it may reach to several hundred miles, as may be seen by the combustion of meteors, which travel at such high speed as to cause tremendous friction with the air. Displays of the Aurora, which depend in some degree upon the atmosphere, have been estimated to extend some 500 miles upward. The height of the loftiest mountains and the greatest depth of the oceans, at a few points, are each somewhat more than 5 miles, measured from the sea-level. Relatively to the size of the earth, therefore, the surface is quite smooth and the oceans but a film. The changes wrought in the original crust by the action of natural forces have been but minor products of greater changes within; yet these details form the graphic record of the vicissitudes through which the globe has passed during many millions of years.

The age of the earth from the genesis of the solar system to the appearance of life cannot be estimated with any degree of confidence; but from other phenomena and the enormous stretch of time necessary to produce transformations on a great scale, it may be implied that the time required to bring the earth from an incandescent stage to one fit for the existence of life was greater than that covered by its subsequent history and may have been many times greater.

Long before the period of historical geology opened the agents of crustal transformation had began their work. Great areas of level surface alternating with rocky heights and lesser irregularities were subjected to the weathering effects of the elements in the same manner as such features are affected now, but with greater intensity. The exposed rocks and mineral formations were eroded by air and water, and the disintegrated particles were blown by the winds and swept by the rains into the valleys and depressions below. Rivers, then as now, emptied their turbid torrents into the oceans, seas and lakes, depositing the sediment in the peaceful depths. These deposits vary in thickness from a few feet to many thousands, and in extent from small to vast, according to their origin and the stability and nature of the bottoms on which they rested. As the materials were drawn from various sources and composed of many different elements in many different combinations, the deposits are highly diversified. After such strata were laid and covered by others similarly produced, the enormous weight of the mass above expelled the water and compressed them into stone. The earliest ones lying at great depths below these accumulations were generally changed in texture by heat. At later periods, when marine life and decaying vegetation exerted their chemical reactions, other types of rock were produced. These comprise a substantial part of the geological formations most serviceable to man.

The great changes which have taken place in the crust of the ageing earth since transforming forces began to operate may be seen from the fact that at least five-sixths of the area now exposed contain stratified rocks of marine origin and probably from much of the remainder similar layers have been eroded. Yet it is quite certain that some portions of the existing continents have never been submerged. While the exposed areas have changed from time to time, the continents have gradually assumed their present form and during later geological ages have apparently become stable. In other words, the so-called continental plat-

forms have existed from the beginning and after repeated subsidence and elevation at length attained a fixed position and support sufficient to sustain the overlying continents permanently above the sea-level, especially as the continents are composed of materials correspondingly less dense than those which form the ocean bottoms—the condition of isostasy, as it is termed. This stable condition is the result of a gradual lessening of the outward flux by the thickening of the crust and the final adjustment of the materials within. This in turn is due to the gradual loss of internal heat. Through unknown eons the globe has been slowly cooling and must at last become a cosmic cinder. Fortunately for the existence of life, it does not depend upon warmth from within the earth, but from the sun, though that body, unless it encounters some other mass, must also in the incalculably distant future lose its glow and become the frigid center of a system whence life has long departed.

As shown by the recurrent rise and submergence of vast areas, the long process of erosion and the shift and reconstruction of the products as sedimentary rocks were accompanied by other forces and changes not less momentous. Perhaps the most significant fact in the whole range of science is that matter, whatever the kind and whether immense or minute in volume, acts in the same way under like conditions. Thus every atom in the complex of things has always obeyed with absolute precision the laws of its being. Actuated by immense pressure and intense heat, the various elements commingled in the earth's interior have been in a perpetual struggle to readjust themselves according to their different properties. At many stages of geologic history, movements so caused, together with volcanic action, have affected the lithosphere. Stupendous quantities of molten matter were ejected from below. The crust was rumpled, folded, cracked and dislocated. In some places the more ancient rocks were thrust to the surface or to the height of mountain ranges. Islands were thrust upward from the bottom of the oceans and in some cases capped

by lofty peaks. Later formations were fractured and contorted and came to rest in every conceivable position. All this was accompanied by corresponding subsidences. In this manner new material was supplied for old processes, which continued unabated, and new depressions were created in which to collect the eroded sediments. In some instances the accumulated strata thus produced are miles in thickness. Mingled with these formations in various ways are the products of volcanic action. In some regions prodigious quantities of molten matter were ejected and before cooling flowed in a more or less liquid condition over the surrounding surface. These areas, of course, vary in dimensions and character depending on the volume thrown out, the nature of the materials composing the outflow and the irregularities of the surface that received them. In many places the molten matter did not overflow the surface, but filled the fissures in the fractured crust, or, by lifting the upper strata, was forced into the intervening spaces.

Such are the outlines of the structural processes. The sequence of the phenomena forms the more difficult and important phase of geologic science.[10]

THE SEQUENCE

Every branch of science necessarily develops a terminology of its own. Not seldom the names of phenomena and things are uncouth compounds of Greek or Latin terms difficult to understand even by one who is acquainted with those languages. Once adopted they enter into the vocabulary of the science in which they are applied wherever it is pursued. This has the untoward result of rendering the language of scientists alien to the general reader. It has come to such a pass that experts in one branch are scarcely intelligible to those in another. Moreover, geology being an old science, shows in its terminology the marks of the stages through which its development has passed as plainly as the strata with which it deals. Geographical names, ancient and modern and of various origin, have come and are still

coming into use as arbitrary labels that have no more intrinsic meaning to the novice than the names borne by ocean steamers or railway coaches. To one who is not adept in geologic science the names alone of its many periods require an effort of memory discouraging to study at the outset. It may be that this method is unavoidable, but it is most unfortunate that a subject so profound in its essentials, so full of interest in its stupendous climaxes, and so vital to a clear understanding of the history of the human race should not fascinate every thoughtful mind and be an indispensable feature in the education of youth.

For many years historical geology, like Christian chronology, has dated from an intermediate point. Thus it is divided into the pre-Cambrian and the post-Cambrian. Cambria was the Roman name for a portion of Wales, and the impressive word was adopted by the British geologists, who were then leaders in the science, as descriptive of the rocks, variously composed, containing an abundance of fossils of the earliest types then known. Although these rocks were discovered in Wales, they of course are found in many parts of the world and always exhibit the same general characteristics. Everything below the Cambrian was styled the Archean.

The Darwinian Theory, which had received powerful but fragmentary support in the geologic record as then disclosed, gave a great impetus to further researches in that field. It was evident that, if the theory of evolution were well-founded, there must have been a long succession of living forms graduating downward from the highly organized forms that appeared abruptly in the Cambrian. This would imply a corresponding lapse of time and an environment that permitted the existence of life. The facts demonstrated since are in perfect accord with theory. To this result American geologists have in a large measure contributed. The means exist here in an eminent degree. Notable among several regions on the North American continent containing the oldest exposed formations is that extending north of

the Great Lakes. They have revealed evidences of such variety and magnitude that the Archean has been divided into two great eras, the Archeozoic (primitive life) and the Proterozoic (less primitive life), both of which have been subdivided into a number of lesser periods, usually named, according to the prevailing system, from their geographical location and the sonority of the terms.

THE PRE-CAMBRIAN

The Archeozoic era is one of the present frontiers of positive knowledge. It is the foundation of all known geologic formations. Its depth is yet unknown, but wherever found it shows the same chaotic mixture of materials obviously thrown out by prodigous convulsions, which probably affected more or less every part of the globe. Inasmuch as an enormous period must have elapsed before this era merged into the next, some of its multitudinous products had time to become weathered, eroded, removed and transformed into sedimentary rocks made crystalline by heat and pressure. The eruptive conditions were not constant, but recurred after long periods of quiescence. Thus a long time—many thousands of years—intervened between the last great convulsions of the Archeozoic and the early Proterozoic. This is shown by the unconformity (as geologists term it) of the line of contact between the rocks of the two eras. The old was worn away, and the exposed strata were rumpled by upheaval and subsidence, leaving a clearly marked and extremely irregular floor for later accretions.

The Archeozoic has thus far revealed no fossils. Even if there were forms of life capable of becoming fossilized, the altered character of the rocks would probably have destroyed the evidence, except in a few favorable locations. It is beyond doubt, however, that life did exist during a great part of this era. Immense beds of graphite found there furnish ample proof. Graphite could only have been formed by the aid of organisms that separated the carbon from the carbon dioxide of the atmosphere and the waters.

It is possible also that other formations, such as marble and certain iron ores, which are found in great quantities in the Archeozoic, likewise originated in the reactions of life.

The Proterozoic was an era of change. Less volcanic than its predecessor, it was more so than succeeding eras; yet it exhibits all the normal characteristics of later time. All the evidence points to general conditions similar to those which have since prevailed. The materials erupted from below were practically the same. The atmosphere was essentially the same, and the waters produced the same effects. The extremes of heat and cold were not materially different, showing that the sun was not obscured by vapor and that its radiation was not greatly different from the present degree; nor was the temperature affected by internal heat. Plant and marine animal life flourished, though there were few varieties and in the simplest forms. These facts appear as clearly in the geologic record as the statement of them appears on the printed page.

The duration of the Proterozoic, as now defined, was so enormous that it probably covers two distinct eras. It is best known in Canada, where its great extent and economic importance have promoted scientific investigation. The early stage was one of erosion. Most of what is now the United States was under water, and no small part of the material eroded was carried there from the north by rivers that formed a wide delta. Then came another upheaval greater than the Laurentian of the preceding era. This new system, called the Algomian, was followed by another vast period of erosion. Again a great mountain range was worn away to its very roots. This long process, aided by local subsidences and invasions of the sea, produced the so-called Huronian series, divided, as such systems generally are, into lower, middle and upper.

The typical character of this great era is seen in the record of almost every feature known to geology. Thus it now appears that in the Huronian is embedded the evidence of

a glacial period, such as was formerly supposed to have occurred only at greatly later times. It is also in this system that the oldest fossils yet known are found—the secretions of certain algæ, coral-like plant masses, comprising immense beds, repeated through thousands of feet. Besides these types, there are many traces of worm trails and burrows and the remains of other lowly orders.

The Huronian was not followed by mountainous upheavals. There were some undulations and warping, but no other great movements in this quarter until the present era. The term Algonkian has been very generally taken to include the entire Proterozoic; but eminent geologists now apply it only to the sub-era extending from the Huronian to the close of the great era. In this sense, the initial series, the Animikian—the name being taken from the Animikie Indian tribe—is of much practical importance. It is made up of various deposits, usually of marine origin, and includes much of the iron-ore that now supplies industrial enterprise in the region of the Great Lakes. Later came a great series of outpouring lavas, less the result of volcanic thrusts than of enormous and occasional discharges through fissures in the crust. These molten masses of the Keweenawan—from Keweenaw Point, Michigan—were of many kinds. Among the manifold rock formations there produced are the rich veins of copper, nickel and silver as well as lesser quantities of gold, platinum and other metals, exploited at the present day.

The larger details of the Proterozoic are presented here because they indicate the chief processes of all later geological periods and thus afford a comprehensive idea of the physical history of the globe during the immensity of time through which the evolution of life has proceeded from obscure and simple origins. This sublime era is of course manifested on all existing continents; but nowhere is it seen in such grandeur as in North America. British Columbia, Montana, Idaho, Colorado, Arizona and the Adirondacks of New York expose huge remnants of its colossal

formations. Its gigantic mountains, probably greater than the Alps, have been worn away, and their mighty stumps bear the varied burdens laid upon them in after times.

The succeeding eras have long supplied the substance of geologic science. The vicissitudes through which the earth and its denizens have passed during this time have been the subject of such thorough investigation since Darwin's day that among men of science there prevails an entire agreement upon every essential feature. In the light of the phenomena that preceded, the successive scenes of this great drama may be sketched in rapid outline.

THE PALEOZOIC ERA

This drama of continents and life in evolution, comprising the sequel to pre-Cambrian time, is divided into three great eras; the Paleozoic, the Mesozoic and the Cenozoic, words formed from the Greek, meaning ancient, middle and recent life. The former is divided into six periods, evidenced on all continents and everywhere characterized by geologists as the Cambrian, the Ordovician, the Silurian, the Devonian, the Carboniferous and the Permian. The introduction of these names gives some token of the beginnings of geology as a science. The term Cambrian—the origin of which has already been stated—was introduced in 1833; the Ordovician, also from a tribe of Wales in Roman times, was applied in 1879; the Silurian, from a tribe of ancient Britons, in 1835; the Devonian, from Devonshire in Southern England, in 1839; the Carboniferous, from its coal deposits, in 1821; and the Permian, from Perm, a Russian section near the Ural Mountains, in 1841. These periods are again subdivided into many lesser ones of local importance with local names. The limits of the six great periods of the Paleozoic have been shifted and defined with the progress of knowledge concerning them, while the lesser divisions have increased in number from time to time as the different formations have been more thoroughly studied.

These investigations are still conducted with zeal, and every year yields new facts to the sum of geologic science.[11]

The chief difficulty has always been in showing the correlation of the strata. Rocks of the same age may be of many kinds and in widely separated regions of the world, hence the precise periods to which they belong must be determined by means other than their composition. This process often presents difficulties requiring extraordinary technical skill, and like all other phases of science, compels correction and readjustment until the stage of positive assurance is attained. One of the principal means of determining the period to which any given formation belongs is the character of the organic remains within it. As these are abundant in all periods since the Proterozoic and clearly reflect the successive forms of plant and animal life, they become a reliable guide to the order of the changes through which the surface of the earth has passed. But this order is now so well established that the study of geology, as such, should no longer be burdened by the details of the variant forms of extinct life which fill so large a space in all works on the subject. These complex features belong to biology in its largest sense, and even there the salient aspects of evolution would be more inviting and generally understood if they were less obscured by such a strange terminology and confusing myriad of unfamiliar species and varieties that the average student is appalled by the very sight of the printed page.

During the Cambrian there were no violent and extensive crustal movements. The surface was not tossed and torn by volcanic convulsions. But in North America, which is regarded geologically as the typical continent, the gradual sinking and submergence of a large portion of the surface exposed at the beginning of the period is the distinguishing feature. It is apparent that a great lapse of time intervened after the last known formations of the preceding era and before this process began. There must have existed a long and progressive sequence of life between the sparse

and simple forms of the Proterozoic and the profusion of the higher invertebrates revealed in the Cambrian. The absence of such series may be accounted for in part by the erosion and destruction of strata that contained the evidence, though it may be predicted with confidence that ample confirmation will yet be found in systems which have been preserved by submergence and covered by other sediments which have also escaped removal.

At the beginning of the Paleozoic the areas above water were quite different in shape and location from those of the later eras. Nevertheless, great parts of the existing continents were always exposed; and they have tended progressively to gain their present form and stability. In other words, the great ocean beds have not radically changed, while the outlines of the continents have gradually been established by the elevation of the interior and the final adjustment of the continental platforms to the forces to which they have been subjected. To illustrate, in the lower Cambrian broad strips of territory, upon which mountain ranges along the Atlantic and Pacific coasts rested later, were depressed and through the hollows flowed the oceanic waters. A similar depression, at a later time the base of a mountain chain extending east and west and connecting the Pacific with the Gulf of Mexico, supplied another channel for the invading tide. Afterward the interior of the continent was flooded. These ups and downs continued until the end of the Mesozoic. The submergences varied in duration and area, but were always sufficient to accumulate sedimentary and limestone rocks thousands of feet in thickness and over a wide extent. When, therefore, it is stated that these overflows took place extensively nearly a score of times after the close of the Proterozoic, it will be seen how continents themselves are the products of an evolution requiring an almost inconceivable lapse of time for its accomplishment.

From a purely geological point of view, the Ordovician was similar to the Cambrian in its main features, showing

the same uneasiness of the continental platforms, but no revolutionary activity, at least in North America. Not until the close of the period did any movements occur that caused great elevation. The Green Mountains of Vermont, the Berkshire Hills and the Highlands of the Hudson are remnants of the Taconic disturbance which then upreared a system of some magnitude extending as far south as Virginia. Similar events took place on all the other continents; the region now occupied in part by the British Islands was probably the scene of most violence. Limestones and shales are characteristic of the Ordovician. The resources then stored up have been of much service in the present age. Oil and gas have been tapped in great volume from the rocks of that period. These hydro-carbons (compounds of hydrogen and carbon) are of marine origin. They were produced by bacterial decomposition of organic matter. The particles of oil and gas disseminated through the rocks in which they were formed, were carried away by percolating water and finally collected into great cavities enclosed by impervious shales. Lead, zinc, manganese, marble, cement, lime and lime phosphate are also obtained from the deposits of Ordovician time.

The general characteristics of the Silurian are similar upon all the continents, so far as they have been studied. The period was somewhat shorter than the preceding ones of this era and records fewer changes. There was but one general submergence of North America, which occurred early; then after a long quiescence almost the entire continent emerged from the waters. The great mass of rocks over which the Niagara pours its torrent was formed during this age of submergence. The seried strata piled high on either side of the gorge present a graphic record of the long process by which the sediments were built up, one after another. Through them the shelf of the Falls has slowly receded. In other localities a similar result, but from a different cause, is shown in the beds of rock-salt and gypsum. These two ingredients usually exist in sea-

water in about equal degree. They are normally found together, if not afterward affected by the action of fresh water, where inland seas were left to evaporate when the elevation of the surrounding lands severed their connection with the ocean. There were considerable deposits of iron-ore along the Appalachian trough and elsewhere. The red fossil-ore (hematite) now utilized in the Birmingham district of Alabama belongs to this period. In many cities stately edifices of limestone and sandstone are modern monuments to the remote Silurian. As large sections of the nascent continents were long inundated and experienced but little volcanic disruption or discharge, the results in all such areas were similar to those in North America—extensive strata of sedimentary rocks as diversified as the materials from which they were derived. Lifted or lowered by subsequent movements, the Silurian deposits, for the most part, have either been stripped by erosion or buried under later accumulations. But wherever they are known they abound with proofs of the multiplying forms of life which then swarmed in the shallow waters of the submerged region where their fossilized remains are found.

In its leading physical features the Devonian of North America resembles the preceding period. The same phenomena of rising and receding waters have left their record behind. The continent that emerged in the later Silurian continued through the early Devonian. Then followed sectional inundations increasing in extent until toward the close of the period, when again the continent became nearly intact. Volcanic action was far more vigorous and revolutionary in other parts of the globe, particularly in western Europe; and it may well be that the rise and fall of the waters in North America were less due to the elevation and sinking of the surface than to changes in the sea-level. Obviously, if the oceanic beds were extensively raised by internal forces, the waters would rise to higher levels and overflow the lands lying below them. There is reason to suppose that such conditions developed many times in dif-

fering degrees through geologic time; and there is no reason to suppose that the crustal movements during the formative eras were confined to those parts which have become continents. The islands of the South Pacific, as well as the maps of paleogeography, show changes in the floor of the oceans sufficient to alter the former strandlines by hundreds of feet.

The most notable exhibit of the Devonian system in North America is in the Catskill Mountains, which resembles in its main features the famous Old Red Sandstone of Scotland.[12] The important gas and oil fields of Pennsylvania, Ohio and West Virginia are also relics of this period. But its chief distinction is in marking an impressive stage in the evolution of life. The back-bone had at last been established, while lungs and brain had begun to bear their part in the scheme of nature. The phase of origins had passed, and the course of development had opened. Vegetation, which started at the water's edge, had become adapted to the soil and gradually spread its multiplying forms of verdure over the bleak and barren lands. The true primeval forests had begun to flourish and become the abode of the invading hosts that crawled out of the water to begin their devious career as the ancestors of the species that now inhabit the land.

The Paleozoic era closed with the Carboniferous and the Permian periods. They were quite similar in general character, though the latter is defined most clearly and extensively in Europe and Asia. It was in the upper Carboniferous that most of the great Coal Measures were formed. Before this phase opened, however, there was a succession of conditions such as prevailed alternately during the Devonian. In North America this epoch is known as the Mississippian. After the emergence of the continent during the later Devonian, inundation began once more, with its usual incidents, in the region of the Gulf and later spread over much of the Mississippi Valley, then through the western trough, styled the Cordilleran Sea, extending from

the Arctic to the Pacific. After this deluge, the waters again retreated, leaving the low-lying exposed areas peculiarly suited to the coal producing agencies that now began their work.

Long periods of luxuriant forest growth on low or swampy lands were followed by entire submergence, so that accumulations of woody matter were covered by strata of sediment. This arrested decay and permitted a gradual alteration of the substance. Under enormous pressure much of the oil and gas were forced out and the residue was slowly carbonized. As might be expected from the variety of circumstances in which they were produced, the coal seams differ in thickness and extent. In some localities the process was repeated many times. In many cases the overflow was fresh water; in others, salt. It is thus apparent that there were many movements of the underlying crust. Low country open to inroad by the sea was flooded through subsidence, while interior lands were covered by the waters of lakes and rivers impounded by the elevation of the channels through which the streams had previously flowed.

During the remainder of the era the typical geological events of the preceding part recurred, but with increasing internal disturbances. In North America the upper Carboniferous, here termed the Pennsylvanian, occurred another wide submergence, followed by a recession of the sea, which became complete in Permian time. The western section from California to the Polar Sea was marked by volcanic convulsions; and in the east broke out the Appalachian Revolution, the effects of which are seen to this day. The entire region from Newfoundland to Alabama was rent and contorted. The crustal unrest in that quarter during the Paleozoic culminated in a mighty cataclysm. The cause was not volcanic, but a gigantic lateral thrust that rumpled the horizontal strata into a mountain system, doubtless equaling in height and rugged grandeur any of the present age. The globe had been slowly contracting, and the surface

could only fit itself to the shrunken earth by folds and upheavals where the push found weakest resistance.

The geologic details of these periods on other continents present many diversities, yet the same essential character. The conditions that caused oceanic overflow and subsidence and finally the Appalachian uplift were present elsewhere and with similar results. Through central Europe and across the British Islands, as well as on every other continent, are the remains of mountain ranges created by the same process of faulting, folding and upheaval. The consolidation of the earth had reached another stage of readjustment by gravitation—a process by no means completed, but at each stage promoting a more definite arrangement of its masses. In speaking of continents, it is not meant that their precise form was the same as now, but that they included all or the larger part of their present features. The excesses now lost were sometimes very considerable. For example, many geologists assume that at some time during the Permian and perhaps from the Devonian, South America, Africa, India and Australia were joined by a prodigious stretch of territory that spanned the now intervening seas. The reason for this theory is solely the known distribution of certain forms of land and marine life assumed to have been impossible without the connection afforded by Gondwana, as this conjectured realm is styled. A situation the reverse of this is entirely certain. An ocean, called the Tethys, extended from western Europe to the Pacific, overlapping southern Europe and northern Africa and passing through central Asia. Its expanse was variable. At times it connected with the Atlantic; and through a depression between Europe and Asia it reached the Arctic Ocean. The Mediterranean, Black and Caspian seas are remnants of this shifting water-way that existed during several periods of the Paleozoic and later. Its changing lines are marked by the sediments it left and the fossil remains of the creatures that teemed in its waters along its shores.

THE MESOZOIC ERA

The Mesozoic, usually classed as the Age of Reptiles, though requiring millions of years for its strange and fascinating history, was not so long as the previous era; and its peculiar interest lies rather in the extraordinary evolution of its life than in its geological features. Its ample records reveal no departures from the general method through which the earth has attained its present condition.

Geologists have long divided this era into three periods: the Triassic, from the old-fashioned, but in most places inaccurate, three-ply denomination of its structure; the Jurassic, from the system as displayed in the Jura Mountains; and the Cretaceous, from its broadcast and distinguishing chalk formations.

The Triassic period was one of comparative quietude. Without extreme crustal movements, there were no new inundations of great sweep. In North America only small areas, chiefly coastal, contain sediments of this time. Elsewhere the general relation of land and sea remained much the same as at the close of the Permian. Volcanic action was here mostly confined to the northwest. It attained great violence in the Alaskan region and extended southward with diminishing force. In the east, igneous rocks of this period are scattered from Nova Scotia to North Carolina; but they were the peculiar sequel to the causes that produced the Appalachian uplift. The stress and strain had not been entirely relieved. New faulting and folding ensued. Thus were built up numerous lesser mountain chains, the vestiges of which still make many a landscape picturesque. The peculiarity of this movement was the outflow of molten matter through deep fissures in the dislocated crust. Great fractures yawned in many places throughout the area of disturbance, and from them volumes of basaltic lavas gushed forth. The most notable example of this phenomenon is seen in the Palisades of the Hudson.

Over the greater part of North America the Jurassic was a period of erosion. The sediments of that time show

a variable submergence of the regions near the Pacific coast; but later the Sierra Nevada range was formed in much the same manner as the ranges of the East had been, although accompanied by great intrusions of igneous rocks. The placer gold of California was the product of slate rocks laid down after these events; but the source of the deposits was concurrent with the gold-bearing quartz veins of the Sierras—fissures in the disrupted strata into which the molten magnas had welled up from below. Europe and Asia were extensively flooded during the Juassic. On the other continents the changes appear to have been similar to those in North America.

The chalk deposits which very early gave its name to the Cretaceous were by no means general among the formations of that period. They are chiefly composed of the shells and skeletons of minute organisms, which have flourished from a very primitive stage in the development of life, but were especially abundant in some quarters during the Cretaceous. The most famous of these deposits are the Cliffs of Dover.[13]

The instability of many continental regions still continued. The transgressions of the Tethys were the greatest in the history of the areas it affected. That part of the Gondwana between South America and Africa was now disrupted and sank beneath the wave. Twice during the period North America was invaded by the sea; though both invasions were in the south and west, where the flood had oscillated so many times before. The northeast was not subject to these inroads; but an extension beyond the present coast-line from Greenland to the Antilles now finally disappeared, leaving some marginal areas of shallow and variable submergence by the Atlantic and the Gulf of Mexico and extending well into the Mississippi basin. These conditions account for the numerous and important deposits of coal during this period. The petroleum of Texas, the sulphur of Louisiana and limestones of the west are also among its economic products.

The period and the era closed with a series of geologic convulsions more severe on the North American continent than elsewhere. The greatest upheaval occurred in British Columbia. It was the beginning of the mighty easterly thrust that was eventually to create the mountain system extending from the Arctic Ocean to Cape Horn. In the northwest the movement was accompanied by enormous lava outflows never surpassed, except in India, where the Deccan lavas of the same epoch spread over 200,000 square miles, in some places more than a mile thick. During most of the Mesozoic the eastern part of the United States, except along the coast, erosion had reduced its rugged features to a peneplain, varied only in localities where the tougher rock masses resisted the wear and tear of the elements. When the era ended there had been another, but not violent, uplift along the Appalachian line, and a retreat of the sea from the coastal plain. This tilting of the surface furthered the work of rivers and streams, which have carved the characteristic features of the eastern landscapes.

THE CENOZOIC ERA

The geology of the Cenozoic, the Age of Mammals, may be sketched in broader outline. The era is divided into the Tertiary and the Quaternary periods, though both terms have become misnomers through advancing knowledge of the pre-Cambrian. They are so embedded, however, in the literature of science that they persist despite their inaccuracy. The Tertiary is subdivided into four epochs, Eocene, Oligocene, Miocene and Pliocene, derived from the Greek and marking gradations of the word "recent." Thus, in the order given, they signify dawn of the recent, little, less and more recent time.

The Tertiary accomplished the entire and final emergence of North America from the waters. The elevation of the interior had already drained the inland seas. There were some marginal overlaps along the Atlantic and Pacific coasts. These shifted back and forth, but gradually lessened until

the present shore line became fixed. The greatest submergence was in the Gulf States and the Mississippi valley. Late in the Oligocene a portion of Florida was an island. Not until the late Pliocene did it become as now a peninsula. Its rise was concurrent with that of the Mississippi basin, which reduced the Gulf to its present general outline, with some marginal variations, until into the present era.

Several times before the Tertiary North and South America had been severed, as shown not only by the sediments deposited in the region of the Isthmus, but also by the sharp breaks in the spread of animal life. In the Cretaceous this chasm was again bridged, only to be broken during the Eocene. Not until Miocene time was the union finally restored. Intermittently through these long ages volcanic violence reigned along the Pacific coast. It attained its greatest intensity during the Miocene and continued into the Pliocene. From Southern Mexico to Alaska at least eleven powerful volcanic centers were scattered. Mount Rainier, Mount Shasta and Lassen's Peak in the Pacific states, Popocatapetl, Ixaccihuatl and Orizaba in Mexico continued their activity long after the Tertiary closed. Indeed, the smoke and fumes of some of them at the present day are a portent of danger. The troubled career of the West Indies likewise culminated in volcanic upheaval, and in South America like phenomena became pronounced. The Andes then began their gigantic ascent. During the Pliocene the Rocky Mountains, which had previously begun to rise, were pushed upward thousands of feet. In other words, the mighty eastward thrust, which began in the late Mesozoic, was renewed with added force along the entire Pacific coast of both Americas, though the results of greatest magnitude as yet were in the north. Then originated the great San Francisco fracture, the immediate cause of many earthquakes which have shaken that region. The catastrophe of 1906 was the result of a slip along that rift, which is a continuing menace to the stability of the adjacent country.

The Yellowstone Park was a product of Miocene volcanoes. In the basin of the Columbia many thousand square miles were covered by lava flows. During the Pliocene, and perhaps somewhat later, the plateau of the Colorado was lifted several thousand feet; and through that rock-bound mass the river has since carved out the Grand Cañon to a maximum depth of nearly a mile and a half—the most extraordinary geologic exposure on the globe.

The cause of these colossal movements was the renewal of the stresses so vigorously shown in the later Mesozoic; hence they were not confined to the Western hemisphere. In the Oligocene the Rif Mountains of Morocco, the Pyrenees of Spain, the Appenines of Italy and the Carpathians of the Balkan Peninsula began to rise. They were followed in the early Miocene by the rise of the entire Alpine system, which reached its full proportions in the Pliocene. As usual in the formation of mountain systems, the Alps were produced mainly by folding. The thrust was from the south, and its force was felt as far north as the London basin. Thus the snow-clad summit of the Matterhorn was pushed bodily from a great distance to rest upon an entirely alien base. It was in the Pliocene that the volcanic districts of the Mediterranean region became active. Vesuvius and Ætna then began their fitful eruptions, so disastrous in historic times.

In southern Asia similar phenomena were repeated on a grand scale. During most of the Eocene the whole region was undisturbed, though flooded to a greater extent than ever before. Then the contraction of the Tethys set in through the process of faulting and folding. Northern India and Burma emerged from the waters and assumed a mountainous aspect. In the Miocene the movement was renewed, lifting the mountains higher and breaking up the Tethys into disconnected basins, of which the Mediterranean is the most important in modern geography. The climax came in the Pliocene, when the majestic Himalayas were raised to the clouds. The stupendous thrust and upheaval that at-

tended it affected the regions to the north as far as Thibet and Mongolia.

The ragged coast-line of eastern Asia, with its extensive fringe of islands, large and small, would alone suggest the vicissitudes through which that part of the continent has passed. The adjacent waters are mostly shallow, so that the variations of the sea-level, from whatever cause, would work corresponding changes in the shores of the mainland. Although the changes have not been studied as thoroughly as in other quarters of the world, enough is known to indicate many and important variations. During the Tertiary the last remnants of the Gondwana sank into the oceanic beds. On the other hand, the reach of water between the Arctic and the Tethys at last closed up. The rise of the Caucasus Mountains, the steppes of Russia and the long sag west of the Urals joined Europe and Asia as a continuous mass.

THE ICE AGE

As in many other instances of geologic sequence, the line of division between the Tertiary and the Quaternary is obscure, because the transition was gradual in those regions not radically affected by the climatic changes that followed. The tumult of the Pliocene slowly subsided and the conditions that were eventually to render the Pleistocene (most recent) perhaps the most remarkable period in geologic history become apparent. From a warm and salubrious climate, a large part of the temperate zone of North America, Europe and portions of Asia were covered with ice. In America the ice sheet extended southerly along an uneven line just below the Canadian border to the Missouri, thence along that river and the Ohio and still eastwardly at about the latitude of Long Island. In Europe it enveloped most of Great Britain and extended thence along an irregular line into Asia. That the conditions which produced this glaciation were general is shown by the fact that not only both polar zones and all regions of high altitude were affected,

but also those parts of South America and Australia lying in latitudes corresponding to those of the frozen north.

In its details the Pleistocene of North America has not been as thoroughly elucidated as that of Europe; but enough is known of its main features to afford a clear idea of what took place. Thus the ice made several general advances and probably others of lesser extent. Inasmuch as life was extinguished under masses of ice several thousand feet in thickness, similar to the glaciers at the present time on the shores of Greenland and Antarctica, there are few fossils to gauge the occurrence. The denizens of the Arctic were pioneers of the ice. Walrus disported on the strand of New Jersey; the musk-ox foraged in Oklahoma; and the wooly rhinoceros, on the banks of the Potomac. The existence of these vast mantles of ice is shown by the debris they left and the changes they wrought in the areas they covered or affected. When they melted and the regions again became suited to life, it again reappeared from the warmer parts to which it had retreated and again gives its testimony where it has not been worn or washed away. Since the evidence of glaciation is always the same, it is often difficult or impossible to separate one glacial stage from another, especially where the products of the intervening time have been removed. It is known, however, that the main inter-glacial periods were much longer than the glacial and also much warmer than the same latitudes are now. The various character of the Pleistocene may be inferred from its outstanding events and its probable duration. The time that elapsed from the advance of the first ice sheet to retirement of the last is estimated at not less than 400,000 years and may have been a million more.

The Glacial Age presents one of the most difficult problems of geologic science, and the authorities are not yet in agreement as to the cause or causes of it. Interest in the question, however, is unabated, and it is furthered by the fact that the Pleistocene, glacial and inter-glacial, includes the early history of the human race. Moreover, many

natural features of the earth's surface as they now exist are due either to movements of the ice-sheets or the torrential effects of their melting masses.

There were two periods of glaciation, more or less important, in the pre-Cambrian. Another occurred in the Permian nearly as extensive as those in the Pleistocene, though more marked in the southern hemisphere; otherwise its chief characteristics were very similar to the phenomena of the later time and were doubtless produced by similar causes.

It is assumed that the ice sheets resulted from conditions similar to those which now produce glaciers. Their encroachment, however, upon the temperate zones and upon areas much less elevated than those upon which glaciers in those zones are now formed indicates a general temperature lower than in the present age. Thus it is calculated that the snow-line descended about 4,000 feet, which might have been caused by a drop of some ten degrees in the average heat from the sun. Glaciers are formed by accumulated snowfall; hence they not only require immense and long continued precipitation, but continuous cold, which can only be found in altitudes above the snow-line. But altitude alone does not cause precipitation. There must be currents to carry a moisture-laden atmosphere; and these in turn are guided by the conformation of the surface over which they pass. The tremendous changes in the topography of the continents after the upheavals in the Tertiary must therefore have been a contributing cause. Likewise the ocean currents are an important agent in climatic conditions; and these currents may have been radically affected by changes in the ocean floors, shores, and channels produced in the same period and in the same way as the changes on land.

It is obvious that immense evaporation from the oceans and the bodies of water inland, which were so great and numerous in the Tertiary that it has been called the Age of Lakes, must have occurred to supply the ice covering many millions of square miles to a thickness of from 4,000 to

10,000 feet. And such was the fact. It is known that the sea-level was lowered from 200 to 300 feet. Theories that climates may have been altered by changes in the orbit of the earth and the tilt of its axis have found no encouragement from astronomy; nor do geologists see any indication whatever of changes in the tilt, if such changes would have wrenched and deformed the crust. However, the argument is still advanced that gradual oscillations of the axis would be caused by tidal action and that when the axis was perpendicular to the ecliptic, during widely separated periods, seasons and differential climates would disappear. The probable variation in the amount of carbon dioxide in the atmosphere at different periods, lessening the retention of the sun's heat, has also been suggested as a cause. While in some cases this may have been one of the features, it leaves other concurrent phases unexplained and is therefore to be regarded rather as an ingenious speculation than a final solution. That an extraordinary amount of volcanic ash in the atmosphere, according to another theory, could lower the effective heat of the sun for ages at a time is quite improbable. From the evidence now available it would seem most likely that the sun has been the main cause of the glacial periods; and this conclusion is supported by the inter-glacial times, which might have been very natural results of increased radiation after intervals of obstruction.

The cumulative effects of the Pleistocene were so great that, after the lapse of from 20,000 to 50,000 years (the estimates vary) since the last glaciation, they yet retain their extraordinary features. Besides the normal movements of the crust continued from the turbulent Tertiary, there were extensive warpings caused by the weight of the ice. But the distinguishing effects of the ice-sheets were due to the advance of the glaciers and the force of the water discharged by melting. These effects would seem incredible were not the evidence so impressive.

The glaciers were thrust forward by additions in the rear, in the same manner as the glaciers of to-day, though on a

vastly greater scale. The lobes were of many widths, from a few miles to hundreds. As the sources of dispersion were mountainous regions, ponderous masses of rock were caught in the advancing sheets and thus pushed or dragged over the surface below, in many cases for hundreds of miles. This process, continued for ages, scored and ploughed the pathways of the movement. Rocks were broken and ground into all manner of debris, ranging from huge boulders to till and clay, forming the moraines that mark the glacial extremes.

The ice-sheets that centered in Labrador were finally dispersed through the St. Lawrence basin and the regions to the south. All the mountain systems of New England and New York, except the Catskills, were wholly buried in the ice. The record is graven on the rocks and the watersheds. The Adirondacks divided the movement in that quarter. One lobe thrust its way through the Champlain valley, and its departing waters passed through the Hudson. Another scoured out the beds of the Ontario and the chain of picturesque lakes in central New York, all much larger than now. Their turbid overflow found the devious channels of the Mohawk and the Susquehanna.

In the west a similar history is unfolded. The Great Lakes, variable and vaster in their original spread, are the work of the glacial epoch. A body of water greater than all these lakes combined came from the dissolution of the Keewatin ice-sheets, which centered in the far north. It flooded the plains of Manitoba, Montana and the Dakotas, now one of the chief graneries of the world. The flow of water from these vast sources developed the master drainage systems of the country. The Missouri and the Ohio were thus given their present courses. The Mississippi was a mighty stream from the place where it tapped the deluge of the north. As the ice retreated the flood abated. The old river systems had been filled with drift and changed to conform to a new topography. The Great Lakes were gradually reduced to their present dimensions, and their outlet

established through the St. Lawrence. Lake Champlain and Lake George were the deeper parts of an inland sea connecting with the Atlantic through the Canadian basin; marine shells and the bones of seals and whales have been found far above the present water-level.

These familiar features of American geography are the most notable relics of the Ice Age; yet they are typical of the results produced in every region that was affected by the torrents discharged from the melting glaciers. Innumerable lakes that still dot the landscape with their picturesque waters had their origin in these floods, while many others have vanished, leaving their alluvial beds to fruitful tillage. Only those remain where the rainfall along their tributaries makes good the loss through evaporation.

It is a fact of profound significance in estimating the factor of time in geologic history that, notwithstanding the many thousands of years since the close of the Ice Age, of which the recorded annals of the human race are but a fraction, the characteristic lineaments of the globe have undergone no material changes. During the late Pleistocene, however, there were many readjustments. The continental elevations during that epoch were followed at the close by general and local subsidence. Land areas and connections had shut off warm ocean currents, thus serving to lower the temperature. The opening of channels, old and new, must have contributed to milder climates. It was then that Hudson's Bay was formed, and the Behring Sea and Straits broke the union between Alaska and Siberia. The land connection between Ireland and Britain sank into the Irish Sea; and that between England and the continent, into the North Sea and the Channel. The Baltic Sea poured into a similar depression. Throughout the Mediterranean changes took place. The Strait of Gibralter opened. Between Italy and Africa the land bridge subsided, leaving Sicily the surviving remnant. Malta became an island. Between Greece and Asia Minor the land gave way to the Ægean Sea; and the Black, Caspian and Aral Seas sank to their present level.

Java, Sumatra and the East Indian Islands were severed from the Malayan Peninsula; and probably Japan from the Philippines. New Guinea and Tasmania were likewise separated from Australia. The modern world had taken the form we know. The present configuration of the lands of the earth and the climates that invest them are still in their youth. What terrestial revolutions the future may bring, one man may guess as well as another. That they will come cannot be doubted.

THE AGE OF THE EARTH

It is obvious from any resumé of the geologic periods through which the earth has passed that time has been the decisive factor. Expressions of magnitude and the marvelous as descriptive of things within common experience are but feebly suggestive of what has been accomplished by elemental matter on the scale of worlds and astronomic systems. Not less difficult to adjust to comprehension is the lapse of time required by nature's evolutions. To the contemplative mind the vistas of the past are oppressive.

Before science revealed the antiquity of the globe and the long processes in the evolution of life, it was convenient to regard the earth as created out of nothing in the twinkling of an eye, and the successive orders of life by separate acts of creation. When at length the truth began to dawn, the problem of time became urgent; and few problems have been attacked with more ingenuity and greater resources, though with inconclusive results. The best solution is as yet only a rude estimate; but it is amply sufficient to satisfy the demand of theory.

The most usual method of computation has been to measure the amount of sedimentation by the average rate obtained through observation of river deltas. This rate, however, supplies an uncertain standard, because the deposits of the different rivers vary enormously, owing to the diverse nature and volume of the materials and the force of the currents. The obverse method is to ascertain the rate of erosion

from observed localities and from it calculate the time for the known extent, as, for example, the gorge below Niagara Falls. The advance and retreat of glaciers has aided in computing the duration of the Ice Age. The Coal Measures and the vast deposits of limestone in every geologic period have also afforded reliable data. Another method of calculation, which is regarded with much confidence, is the salinity of the oceans, assumed to have come from the exposed lands. The results thus obtained accord very well with those attained by other means. A few years ago a precise calculation was expected through the radium content of certain rocks; but more advanced knowledge of radioactivity has rendered this method of doubtful value. Nevertheless, it must be that the *x* of this problem will eventually be found. All the other factors are present. The earth in all the variety of its outer formations is known, and the evolution of life is certain. Neither the earth nor life as they now exist would be possible without the lapse of sufficient time.

The leading authorities assume the lapse of at least 80,000,000 years since the beginning of the sedimentary rocks of the Archeozoic—an adequate time for organic evolution. Probably the great majority of geologists would adopt a much higher estimate, and some would increase it many fold. Certainly no reasoning mind can question the vastness and plenitude of time as a factor in the history of the earth.

CHAPTER IV

WAYS AND MEANS

WATER

SCIENCE is always confronted with the tangible. Speculation is therefore restrained by unyielding realities. If the efforts to explain are not conclusive, they must persist until theories merge into facts.

The special sciences are but systems of related phases. They begin with assumption of the fundamentals and end with concrete results; and the results so accomplished are attested by the progress of positive knowledge and the manifold achievements in the industries and the arts. Technicians eagerly await announcements by the great seekers for principles, and the by-products of their researches are turned to account in the factory, the mill and the market-place.

To one wholly unversed in the principles of physics and chemistry the components of this world of ours, familiar as many of them are, present puzzles most intricate and obscure. The literature of chemistry (with its appalling terminology of various origins, and its multifarious laws, often named after their discoverers) is in an alien tongue, and its ideas are as those of another sphere. However, it is some comfort to know that most of this enormous lore is useful only to the technician and the historian of opinion.

Physical chemistry, though the youngest of the greater sciences in designation, is the oldest in its sources. Interest in matter, the materials of existence, was necessarily aroused at the earliest dawn of intelligence and has steadily increased at every stage of mental development. As knowledge of foods, clothing, weapons, ornaments and medicines extended, civilization progressed. This result was attained precisely in proportion as mind reacted upon matter and

brought it into service. During the thousands of years that elapsed from the practical beginning of chemistry to the opening of the nineteenth century the underlying principles were scarcely exposed.

It is not surprising that the ancients regarded water as the basis of life. If among essentials one thing can be more important than another, water is the principal operative factor in the conditions of our world. Yet it is a striking commentary on the slow progress of scientific chemistry until modern times that not until well within the eighteenth century was oxygen isolated and then found to be a constituent of the atmosphere. Then followed the discovery that water is composed of two gases, oxygen and hydrogen. Necessarily it was not until this period that the phenomena of combustion began to be understood.

From the human point of view, water is the great miracle of nature. First in importance is the fact that its properties are effective within the same limits that bound the existence of life. It is the greatest of all solvents and therefore the cause of most of the chemical reactions essential to life. The reasons for this were not apparent until long after the true nature of water became known, when the progress of electrical research began to explain the constitution of matter. Of the more common liquids, water has the highest dieletric constant. It contains the largest number of simplest chemical molecules. It possesses the two most important and the swiftest ions—one producing all the acids and the other all the bases. These energies give water its great solvent power. It dissociates many of the compounds with which it comes in contact and is the chief agent in causing new arrangements according to the elements involved. Thus originate, for the most part, the complex combinations—new substances—required in the production and maintenance of organic structures, as well as the chief transformations of the earth's surface.

The permanence of water is another characteristic that renders it so important in the scheme of things. No com-

pound is more enduring through the varied conditions to which it may be subjected. Whether as ice or liquid or steam or highly heated vapor, its essence remains unchanged and the bonds of its union unrelaxed. Whatever may be its present relations with other substances and combinations, it has retained its true character in countless others through the course of time; for during geologic time, the volume of water has remained practically constant and has ever been marvellously adjusted to the needs of the earth as an abode of life.

Another of its peculiar properties, and one possessed by few other liquids, is that though it contracts until the temperature lowers to 4 degrees centigrade, it then expands until it reaches the freezing point. It is for this reason that ice floats. If it contracted it would become heavier than the liquid and sink. The greater bodies of water would rapidly accumulate ice that the most torrid summers could not melt. Life in the oceans, seas and lakes, would have been impossible and doubtless the effect on the atmosphere would have glaciated the continents and prevented geological changes that are normal under the conditions that prevail.

The chemical nature of some of these transformations should be clearly understood because of their great importance and the immense scale on which they are wrought. In addition to water the prime factors in these processes are oxygen and carbon, the latter being effective in conjunction with oxygen as carbonic acid gas—carbon dioxide. To illustrate the complex preparation of primal matter for organic uses, both as a habitat and as materials for the chemistry of life, take the case of an extensive mass of volcanic lava ejected from the interior of the earth where its changes were more physical than chemical. In the molten state it was solvent; the original components were fused and blended more or less completely. As soon as it was exposed at the surface chemical action began. Greedily attacked by oxygen, which of all the elements unites most freely with the others, the simpler substances were con-

verted into higher ones by oxidation. Water promptly lent its efficient aid and yet other combinations were produced. Much of the matter that was still able to resist these reactions yielded when carbon dioxide joined the assault. This matter was thus brought into solution and then built up into carbonates suitable for organic assimilation.

The greater part of the rocks forming the continental masses is composed of feldspar containing silicates of alumina with lime, soda or potash. Under the reaction of aqueous solutions the potash is removed and converted into soluble forms that freely enter into vegetable growth, and upon the vegetable products animals directly or indirectly subsist. When organisms die and decay the same materials are again in condition to renew the organic cycle.

One of the most important geologic features is the result of this process of disintegration and solution followed by organic consumption of the lime so dissolved. The carbonic acid gas was originally exhaled for the most part by volcanic means; and very probably the atmosphere contained much more than at present. Natural surface water acquired more or less of this gas in solution. Some is gathered by the rainfall in its passage through the air and some during its percolation through the rocks and soil and much is supplied by decaying vegetation. Many of the products of such solutions are ultimately drained into the seas, where the limestone rocks, which exist in great profusion and variety, have been formed from remote geologic time. They are composed mainly of carbonate of lime, forming the mineral known as calcite. The lime in the original drainage is usually in the more soluble form of bicarbonates, which is therefore more readily assimilated. These are reconverted into carbonates by myriads of minute organisms whose remains are readily distinguished in the rocks they have created. The dolomite rocks, which are much harder, are limestones into which carbonate of magnesium has afterward been infiltrated.

The immense geological effect of the solvent action of water and carbonic acid is furthered by the composition of

another type of secondary rocks. Granite contains various combinations of quartz and feldspar. When decomposed, the feldspar, in a finely divided state, becomes clay; and the particles of quartz become sand. When masses of sand were so situated that they were impregnated with solutions of carbonate of lime or magnesium or both under the weight of other geologic strata they were cemented together thus forming the sandstones.

It is apparant, then, that the soils are the product of chemical action mainly. The raw materials are chiefly sand and clay, which of course exist in great abundance and variety. They are the first results of the decomposition of the rocks. Loam is merely a mixture of sand and clay. Marl owes its character to the carbonate of lime it contains. Muck is a mixture of earths rich in humus, which is mainly carbonaceous material from decaying vegetation. From these simple facts it is obvious that what is known as agricultural chemistry has a very real basis and a very great utility in determining the resources of the soils, their availability for tillage and the treatment they require to promote their fertility.

These examples are given to illustrate the more conspicuous results of the greater chemical reactions which have made the earth a habitable planet. Starting with a heterogeneous crust, vast areas of crude elemental matter in all manner of sheer physical confusion originating in the molten flux, the cooled masses have been brought by natural chemistry into the diversified condition that now exists.

THE LAWS OF MATTER

There is no explanation as yet of the relative proportion of the elements as they exist in the known world. Oxygen is by far the most abundant, being estimated at very nearly 50 per cent. of the total. It comprises most of the atmosphere and also exists free to the extent of about 23 per cent. by weight. In pure sand and clay and many silicious rocks it constitutes about 53 per cent.; in limestone, about 48 per

cent.; and in other materials it is present in a similar degree.

The next most abundant element is silicon, which in nature is always combined with oxygen. It amounts to about 26 per cent. Hydrogen constitutes about 1 per cent. and carbon about 1/5 of 1 per cent. The other elements exist only in relatively small quantities. Hydrogen is almost entirely in combination; hence it has been suggested that if the amount were 10 per cent. greater its combination with the existing free oxygen would have formed water enough to submerge most of the continental areas. Yet this peculiar adjustment is not more striking than the volume of the atmosphere. If it were one-half of what it is glaciation would have begun long before it did and be unceasing.

What are these elements that so indifferently, according to the conditions, compose suns, planets and living things? This is and always has been the master question of science. The ingenious Greeks conceived of matter as made up of ultimate particles, which they called atoms, probably borrowing the idea from the more ancient Hindus. But, as with most other generalizations of that period, this was merely a guess. The Greeks were much more keen in speculation and argument than in physical demonstration. In this loose form the idea long persisted without further development. It was not until chemistry began to assume a scientific character that the atomic theory took a definite form and became an efficient medium of chemical practice. Announced by Dalton in 1803, it soon gained general acceptance because it worked; and for nearly a century the atom, though hypothetical, was regarded as the very real and irreducible minimum of the element to which it belongs.

No other hypothesis ever devised has been so fruitful of practical results. In this respect it has even surpassed the theory of the ether, as imporant as that has been in discovering the laws of radiation. The science of chemistry has been chiefly due to the application of the atomic theory; and whatever may befall the theory as such, it will continue as

the practical basis of applied chemistry in all its branches. This is because of the fact that the unit of the atom holds good as the proximate constituent of matter, whatever may be its ultimate nature and composition.

The atomic theory assumes that each element is composed of ultimate particles precisely alike and indivisible. From this logically follow the fundamental laws of chemistry. If the atoms are indivisible they are indestructible; hence the law known as conservation of mass. The atoms of each element being alike and indestructible, a pure compound always contains the same elements in a constant ratio by weight; hence the law of definite proportions. For like reasons, whenever more than one compound is formed from the same factors and one of them is fixed in amount, the quantities of the others in the different compounds vary in simple ratio; hence the law of multiple proportions. Inasmuch as chemical changes involve the addition or subtraction of atoms or molecules—that is, elements or compounds—the differences are found by computation based on weights. The relative amounts of elements which combine with a fixed amount of oxygen are also equivalent when they combine with other elements. This law is known as that of reciprocal proportions. But the principle of greatest practical importance is that of combining weights. The compounds of pure chemical compounds may be accurately expressed in terms of fixed numbers, or multiples of them by integers, each element having its own combining weight. The equivalent weights represent the weights of the elements in combination with oxygen fixed at 8, while the atomic weights are based on oxygen at 16, for practical convenience.

These laws obviously take substances into account only according to their respective weights; and as the various elements all have different weights, it has been necessary in exact chemistry to know them with as nearly absolute precision as possible. This has required the utmost nicety of determination. The weights have been repeatedly redetermined and the corrected list standardized the world over. Yet the

table is ever subject to revision and will be until substantial error is removed, though absolute precision on this basis may be impossible.

If the science of chemistry had depended wholly upon knowledge derived from the study of solid substances, but slight progress would have been made. From a technical point of view, little is known about the internal mechanism of matter in a solid state. The geometrical forms in which it crystalizes are known and also something about the way in which solids conduct different forms of energy—light, heat and electricity; but the molecular weights of the simplest solids are unknown. There are no reliable means at present of finding out the formula of such a common thing as rock-salt or ice.[14]

It was seen very early that in every chemical reaction heat is produced or absorbed, and that light or electricity may also be produced according to the conditions. This showed that in every such reaction there are two kinds of changes—of matter and of energy. Naturally the material changes were first studied, because they were the most obvious; and both kinds of changes are most readily revealed in solutions. Thus at the present day the major part of chemical investigation is carried on by means of solutions. This indeed is the great medium of nature. Not only are solutions the chief vehicles of geologic change, but of the organic processes as well.

Yet it was not solutions that gave direction to the modern trend of chemical theory. This factor was gas. As any gas when confined exerts a pressure, the explanation was eagerly sought; if found, it would manifestly lead toward explanation of the nature of matter itself. It was long supposed that some gases are not capable of being changed into liquid or solid form; but the fact was finally demonstrated that every gas, under suitable conditions, can be liquified. When it was found that hydrogen, the lightest of all known elements, is present in a great diversity of solid combinations, and that all solids can become gaseous, the conclusion

was inevitable that there are no essential differences in matter of whatever kind.

The analogy between gas and other phases of matter is apparent from the laws of their behavior. Every gas has its own degree of pressure, which never varies under like conditions and is proportionally affected by the compression and temperature to which it is subjected. Even before he announced the atomic theory, Dalton had discovered that in any mixture of gases which do not combine chemically each gas exerts the same pressure as if it were alone, and that the total pressure is the precise sum of the separate pressures. Nor is this property affected by the mixture of gases with liquids. When a gas is dissolved in water, the quantity that can be dissolved varies with the pressure of the gas; and with a mixture of gases so dissolved, each gas acts independently of the others. Quite significant of the quality of motion necessary to such phenomena is the equally positive law that the volume of a gas varies inversely with the pressure.

In 1811, Avogadro, an Italian physicist, announced the law that equal volumes of all gases, under like conditions of temperature and pressure, contain approximately equal numbers of molecules. A molecule is the smallest mass of an element or a compound which can exist by itself. The weights of gaseous molecules are directly proportional to the specific density of the gases, and from the known density of the elementary gases it follows that many of them consist of molecules of more than one atom. A large proportion of the molecules move in groups which become smaller with increase of temperature. Thus a molecule of water in the state of gas consists of two atoms of hydrogen and one of oxygen. As liquid at the ordinary temperature of the air the molecules join or move together in combination of two or more. The law of Avogadro has been the most important means of correlating chemical facts and is thus fundamental in practical chemistry. Yet it was not until about 1860 that the principle was generally accepted, because a clear distinc-

tion had not been drawn between the molecule and the atom as the physical unit of matter.

The property of motion possessed by all atoms in a gaseous or liquid state is further illustrated by one of the most important of organic processes. This is known as osmotic pressure (from *osmosis,* Greek for "a push"). Growth is made possible by means of appropriate materials being taken from the environment in a gaseous or liquid condition. The necessary matter in solution is taken into the system, animal or vegetable, by means of membranes which are permeable only by the substances required by the organism, the others being normally excluded. The circulation of the blood, including all the phenomena of breathing, is the most notable example of this process. The diversity of function shown by the membranes is one of the wonders of nature; yet the process itself is simple in principle. Thus it is readily available in chemical work and is accordingly employed to separate certain ingredients in solution. The action proceeds according to laws analogous to the diffusion of gases.

The osmotic pressure varies directly as the concentration, and the pressure of a solution of uniform strength increases proportionally with the temperature. Moreover, the osmotic pressure of any substance in solution is the same as it would be if present as a gas in the same volume as that occupied by the solution, provided the solution is quite dilute. Solutes (the substances dissolved) when present in the ratio of their molecular weights in equal volumes of the same solvent exert the same osmotic pressures. These laws may appear somewhat technical, but they are quite intelligible and all bespeak the inherent motion of atoms and molecules when they are so circumstanced that the motion is free to exert itself.

The phenomena exhibited by matter in all its phases, as systematized by these laws (and others of a highly technical character) have occasioned two great generalizations—the kinetic theory of molecular motion and the conservation of

energy. It is thus assumed that all matter is composed of separate molecules which are in constant motion; that they are perfectly elastic, and in gases, wholly independent; that in liquids and solids this free motion is limited by cohesion, and the speed of the motion is changed by temperature. The particles being perfectly elastic, their energy is never impaired, and the different forms of the energy are mutually convertible one into another. It follows that, whenever an amount of energy is produced or absorbed in the formation of a compound, exactly the same amount is required to separate the constituents. To illustrate these principles by a familiar instance, a given quantity of coal by burning produces the same amount of energy—which in turn may cause heat, light or electricity—as was taken, directly or indirectly, from the sun to produce the coal; and the components released by combustion are then free to renew their activity by producing new combinations without loss of any part of their constitutional energy.

It will now be seen by those who were not familiar with the kinetic theory of gases why the moon has no atmosphere and that of Mars has become depleted. Free motion is always in a straight line; variations are caused by other forces acting upon it. The molecules of a gas move in all directions; but most of them collide with one another and rebound or are deflected. It is this motion of the innumerable particles that causes the diffusion and the consequent pressure when stopped by the container. If the moon ever had an atmosphere it must have been speedily lost. The outer part of an atmosphere is not only the most rarified, but it is composed of the lightest free gases of the whole. As the external particles moving directly outward were no longer impeded and were moving with a velocity greater than the gravity of the moon could arrest, they plunged into space. This process continued until all the gases were lost. The same principle of course applies to all minor astronomic bodies. Mars, being larger than the moon, exerts a greater power of attraction, and its loss of atmosphere has been pro-

portionally slower. The earth is massive enough to have held its atmosphere, which emanated from within, without substantial diminution.

That matter never loses its potential energy is aptly shown by the materials contained in the meteors. These materials are held intact and inert in the absolute cold of space during the hundreds of millions of years since the formation of the solar system; yet the instant they come in contact with the air their latent energies spring into action. After blazing their way to the surface of the earth any fragments that remain are as amenable to chemical action as any other material that might be converted in a crucible or a solution.

Despite the steady progress of general chemistry during the first half of the nineteenth century, it gave little promise of becoming an exact science. Its laws were largely empirical and its science chiefly in classifying the already immense and constantly increasing multitude of separate facts. Several hitherto unknown elements had been discovered, and a great number of compounds, of which the composition and properties were unknown or not fully recognized, were identified and analyzed; and the process is yet far from exhausted. The labor devoted to these researches and explorations of matter occupied the greater share of attention. The field of organic chemistry enormously widened. Thousands of organic compounds had become definitely understood. For a long period there was supposed to be some vital distinction between organic and inorganic matter; but the progress of investigation revealed no differences in the principles of their combination and the presence of none but familiar elements. When it was found that many of the organic compounds could be duplicated by synthetic methods —literally manufactured from the elementary ingredients wherever obtained—organic chemistry came to signify the system of compounds in which carbon is a factor. Some aspects of this branch of chemistry will be more serviceably presented in their biological relations; but the main fact is significant here as showing that all matter, however com-

bined, obeys the same laws of chemical change and is composed solely from the same body of primary elements. Naturally this gave a powerful impetus to operative chemistry in all its phases and thus multiplied the concrete results of chemical theory. Practical chemistry then began that expansion which has been quite unexampled in any other sphere of effort and has become an adjunct of virtually all the most important arts and industries.[15]

THE ELEMENTS

It will be recalled that when the spectroscope was introduced the possibilities of astronomy were greatly enlarged and the science began a new development. A similar though lesser result followed in physical chemistry. The spectroscope supplied a laboratory test that was even more infallible than in astronomy for detecting the presence of any element from the spectrum it gives when incandescent, the greater certainty being caused by the absence of intervening atmospheres or stellar gases and the proximity of the substance yielding the light being analyzed. The theory of the spectral lines is the application of an ordinary mechanical principle. Light, being a series of waves of different lengths, according to the color of the rays, but all having the same velocity, is neutralized by passing through a gas containing the same elements that produce the light, the waves being stopped, absorbed, because the intercepting gas contains molecules having the same speed of vibration as those which yield the corresponding portion of the spectrum; hence the blank or dark lines across it. On the other hand, bright-line spectra show the sources of the light to be such that they yield only part of the rays necessary to produce complete spectra, which can only result from white light. When a substance becomes gaseous and the gases are heated to incandescence, their spectra are not continuous, but consist of separate bright lines. The number and position of these lines depend on the color of the total light emitted, this color being due to the particular variety of wave-lengths combined

in the light. Since the atoms of each of the different elements have a distinctive vibration, unlike that of any other element, the lines represent different wave-lengths, which have their individual places in the spectrum, where they are identified with absolute precision. From these facts it will be seen how important has been the function of the spectroscope to chemistry and physics.

It is now very generally assumed that there are 92 elements, including certain of the group produced by successive transmutations from uranium and thorium. All have different atomic weights, ranging from 1.008 for hydrogen to 238.5 for uranium. Only four between hydrogen and lead await discovery, while two gaps in the radioactive group are yet unfilled. This progression early invited efforts to adjust the elements then known to a system based on an orderly arrangement of the atomic weights. Several attempts were made to devise such a system, but the facts seemed too obstinate until Mendeleéff, an eminent Russian chemist, proposed the so-called Periodic Law.

If the elements are arranged in the order of their increasing atomic weights, the properties vary from member to member of the series, but return to nearly the same value at certain fixed points in the series. It thus appears that, with certain exceptions, every eighth element so arranged has similar characteristics. All the members of each group tend to possess the same valence or combining power and their compounds to resemble one another chemically. Moreover, this family resemblance is seen not only in their chemical but in their physical properties, such as specific heat, melting point and so on. Certain of the elements, it is true, do not appear to conform to the periodic law; but its application is so striking in most instances that the exceptions may yet be explained and brought into harmony with the rule. Mendeleéff himself foretold that certain vacancies in the list of elements then known would be filled by the discovery of elements with the missing weights and with properties which he specified. Some years later the rare elements

known as gallium, scandium and germanium were discovered possessing the weights and properties predicted by him. Besides these, the inert gases of the argon group—helium, neon, argon, krypton and xenon—were found partly as the result of search for the missing atomic weights, which they quite accurately fulfill.

About 1912, Moseley, a young English scientist, made the brilliant discovery that, arranged in the order of the increasing frequency of their characteristic X-ray spectra, all the known elements, so far as they have been examined, form a simple arithmetical series, each member of which is obtained from its predecessor by adding the same quantity. This fact would indicate that the inherent electrical energy of the atoms is the source whence all their properties are derived. Thus it is in physics, the science of energy, rather than in chemistry that the ultimate is to be sought. This brings us to the subject of electricity as the universal and dominant factor in the constitution of matter and the medium of the revelations which have been made in recent years.

ELECTRICITY

The progress of modern chemistry has been practically coincident with the development of electrical science, though in the early stages the fundamental connection was not fully perceived. In 1750, when Benjamin Franklin made his experiments and announced the dual nature of electricity, positive and negative, chemists were only beginning to grasp the significance of some of the more obvious properties and relations of matter and were quite without any clear conception of the factors underlying the phenomena of chemical reactions. It was not until 1799 that the production of an electric current by chemical means was discovered by Volta, who produced that result by alternate plates of copper and zinc separated by layers of cloth saturated with salt water or sulphuric acid. This was suggested by Galvani's famous experiment in 1790 (following what he noted through a

casual incident), causing the spasmodic contraction of frog's legs by connecting the nerves and muscles with an arc of two metals.

In 1800, by the use of the voltaic pile made with numerous silver and copper plates and cloths wet with salt solution, water was decomposed. This operation, now so simple and familiar, was one of the most important discoveries in science. It changed the whole trend of research which has led to the chemistry of the present day. The atomic theory itself was prompted by it. The experiment was soon tried with various materials and the process and the principle of electrolysis established with far-reaching results in both practice and investigation.

Despite various theories advanced to account for it, the cause was not recognized until in 1833, when Faraday proved that the source of the energy was in the formation of zinc sulphate and the liberation of hydrogen through chemical change. The conversion of chemical energy into electrical energy is shown by the fact that the quantity of the substances decomposed is exactly proportional to the amount of electricity passed through the solution affected, (the electrolyte). Moreover, if the same current is passed through a series of electrolytes, the quantities of the various materials liberated are proportional to their chemical equivalents.

It was long assumed that the change was due to the breaking assunder of the molecules of the substances decomposed; but, in 1885, Arrhenius, an eminent Swedish physicist, proposed a new hypothesis, which is now accepted as best explaining all the phenomena. By this hypothesis, the current passing through a dissolved or melted electrolyte simply directs the ions according to the electrical charges with which they are already invested and causes them to be discharged and thus restored to the common neutral state at the terminals of the current where they appear. As this process will not be clear to those who have not followed developments in this field during recent years, it

is needful to define some of the terms to which the new discoveries and new theories have given rise.

The Greek language, as usual, has supplied many of these terms. The word "electricity" itself is from the Greek for "amber", because of the well-known power of attraction possessed by that substance when rubbed. The word "electrolyte" is a compound of the words for "electric" and "solution", thus defining either the solution or the substance added to the solvent to produce what is termed a conductor of the second class.

It should be stated in this connection that most substances —nearly all pure liquids, including pure water, the non-metallic elements and most dry compounds—are non-conductors of electricity. Substances that permit the passage of the current—for the most part, metals and their alloys—are known as conductors of the first class. All the electrolytes are conductors of the second class. They allow the passage of the current, but at the same time are decomposed by it or cause the decomposition of the terminals. The electrolytes are acids, bases, salts in solution or water highly heated.

The term "electrolysis," the process of this decomposition, is aptly derived from the verb "to lose," combined of course with "electric." The terminals, at which the current enters and leaves the solution, are called electrodes, another descriptive compound of "electric" with the Greek noun for "path" or "road." The electrodes are either cathodes (downward paths) or anodes (upward paths). The positive elements collect at the cathodes and the negative (non-metallic elements or radicals) at the anodes. Thus when the solute is decomposed into two kinds of materials they move toward the respective electrodes. In this condition they are termed "ions," from the Greek for "goer" or "traveler."

The phenomena of the ions, as explained by Arrhenius, had long been studied in other conditions. By inserting the electrodes in a sealed glass tube filled with air at ordinary atmospheric pressure and increasing the force of the cur-

rent to a certain degree, the air is unable to bear the strain and a spark is produced. If the air or other gas is expanded by removing a portion with a pump the character of the discharge changes. The manifestations of light and movement thus alter with the progressive rarity of the gas. Beyond a certain degree of exhaustion of the gas the discharge refuses to pass, though the highest attainable vacuum still contains many millions of molecules per centimeter. When the current and the rarity of the gas are suitably adjusted the cathode gives rise to particles that move in straight lines and with great speed. As they strike the end of the tube the glass becomes phosphorescent. If a sheet of platinum, or of certain other substances, is suspended between the cathode and the other end of the tube a shadow is cast. If the particles are focused upon an object its temperature is increased, and in many cases chemical changes are produced. They pass through thin sheets of metal, but are absorbed by thicker ones.

These effects and others scarcely less remarkable naturally evoked profound interest and study; but the precise cause was not determined until 1897, when J. J. Thomson, by highly ingenious and intricate methods, demonstrated the entity of the electron. The name antedated positive knowledge of the thing itself. It was suggested in 1881 in recognition of the principle that alone seemed to account for the phenomena.

The properties of the electron are independent of the nature of the gas and of the material of the cathode. Similar particles are emitted from the inert elements of the argon group, from many solids, metals red-hot or illuminated by ultra-violet rays, and radioactive materials. They no doubt are an important factor in many natural phenomena as yet obscure. It has even been surmised that the aurora is produced by electrons discharged from the sun and moving under the earth's magnetic lines of force.

The mass of the electron, as now determined, is $1/1845$ of the hydrogen atom. "Imagine," said Lord Kelvin, "a globe

of water or gas as large as a football to be magnified up to the size of the earth, each constituent molecule being magnified in the same proportion. The magnified structure would not be more coarse-grained than a heap of footballs." In gases, of course, the molecules are much further apart than in liquids; and in liquids much more so than in solids. When it is stated that 40,000,000 molecules of air arranged close together in a line would extend only one inch, the infinitesimal size of the electron becomes inconceivable by our ordinary senses; yet by the perfection of scientific methods it is measured with a degree of accuracy that admits of no question.[16]

The ion may be an atom or a molecule, such a hydroxl, a radical consisting of one atom of hydrogen and one of oxygen. When hydrogen ions and hydroxl get near one another they instantly fly together, forming a molecule of water. The positive and negative electrical forces are perfectly balanced. When, therefore, molecules are neutral, as matter in a normal state always is, the positive force and the negative electrons with which they are invested are balanced. The effect of the current is to disturb this equilibrium which is soon restored when the current ceases.

This action, and many others of similar kind, lend extreme probability to the view that most of the phenomena of nature are due, in the last analysis, to electrical attraction and repulsion. Perhaps the most singular circumstances in electrical manifestations is that, so far as known at the present time, so-called positive electricity never leaves the atom. The positive electron, if such there be, is unknown. The work appears to be performed wholly by the negative electron, which is detached and added with perfect facility. Negative electricity, then, exists, only in the form of electrons. Normally an atom contains a certain quota of positive electricity and a sufficient number of electrons to neutralize it. If by any means an electron is added or released, the balance is disturbed.

The metals, as a rule, exert but a relatively weak attraction on the electrons, hence they are better conductors than

the non-metals, though variable in this respect. A current of electricity is caused by the passage of the electrons through the atoms or the spaces between them. The material movement of the electron is quite slow, only a small fraction of an inch per second; but the impulse is communicated from electron to electron with precisely the same velocity as light. Thus light, heat and electricity are kinetic kindred, and, in the ultimate, through the activity of the electron.

It may be assumed that the radiant energy of the sun is due to the vast number of electrons it contains in a mobile state because of the intense temperature of that body. Since they exist in great numbers in the substance of a metal, it might be expected that, if the metal were highly heated, some of the electrons would pass off into the surrounding space; and this is readily proven to be a fact. Under such conditions, the emission of electrons is analogous to the evaporation of a liquid.

The various phenomena of electrical motion, proceeding from the vibration and impulse of the electrons, are in their radiant characteristics like those of light and therefore exemplify the same laws of reflection, refraction, absorption and variable speed through different substances. And it is not unlikely that what is known as chemical affinity is the product of electrical action—positive elements combining freely with negative, this attribute being most energetic as the condition of the temperature becomes most favorable. Thus common salt is composed of the positive element of sodium and the negative element of chlorine. In view of such phenomena, it is not surprising that the hypothesis should have been ventured, far in advance of demonstration, that throughout the universe there are but two absolute elements, positive and negative electrical charges.

THE X-RAYS

The study of the electron, its entity and functions, was greatly promoted by the phenomena of the X-rays and radioactivity, made known shortly before the electron was

isolated and measured. The discovery of the X-rays, in 1895, was received with more acute public interest than any other scientific announcement had been since the invention of the telephone. The fact that rays had been found which though invisible to the eye, penetrate certain substances and affect the photographic plate, seemed the crowning achievement of a scientific century. But, despite the wonder of the discovery and the practical uses to which it was soon applied, its true scientific import was the light it shed upon the fundamental sources of nature and the constitution of matter.

The X-rays are produced whenever the cathode rays strike matter of any kind. They pass with little detriment through flesh, paper, wood and many other substances, including metals of small atomic weight, such as aluminum; but they are quickly absorbed by metals of high atomic weight, such as platinum, gold and lead. They are not material, like electrons, but are the result of motion produced in the target of the cathode rays and therefore possess the same characteristics as those of light; but their wave-lengths are much shorter. For years no method was found to show that the X-rays proceed according to the familiar laws of light. No surface smooth enough had been used, and no material with sufficiently fine and regular grain to diffract and polarize them. In 1912, however, the difficulty was resolved through the use of crystals. By this method a new and remarkable field of research was opened, and the atomic structure of matter was visibly demonstrated.

Scientists had long regarded crystals as being very tangible evidence of atomic structure. That each of the very numerous substances which crystallize under suitable conditions should assume its own type of formation, was viewed as a plain indication that the different forms are due to definite and corresponding arrangements of the atoms composing them. And this was shown to be true by photographs taken by means of the X-rays. It thus appears that the atoms arrange themselves in perfect planes and in a definite order in

each kind of crystal. Because of the definite positions of the atoms, the crystal operates like a nearly perfect optical grating of three dimensions. When, therefore, the X-rays are passed through it they reveal definite patterns caused by interference. By examining the position and intensity of the spectrum thrown by the crystal the distances between the successive planes of the atoms are computed.

This method of investigation is still in its early stage and promises to yield even more fruitful results. Already it has been applied to some forms of liquid produced from certain organic substances heated slightly above the melting-point. The crystalline arrangement found there can be altered by pressure; but the molecules tend to restore themselves to the ordered pattern where the process can freely exert itself. The laws that govern the manifold arrangements of the atoms in their ordered combinations, fixing their places and holding them in equilibrium apart from one another are as yet wholly unknown. After what has already been learned as to the nature of matter, the impossible cannot yet be delimited.

No less obscure is the system which underlies the vibrations of the atoms. The spectra of the various elements contain tens of thousands of lines, each one of which represents a different period. In the case of carbon or iron alone the periods amount to thousands. Since each period is invariable whenever and wherever produced, there must be a universal cause for each of these multifarious activities. As remarkable as the results of spectrum analysis have been, they fail to elucidate what are assumed to be complicated secondary vibrations within the atoms. Nor is the explanation of magnetic phenomena much further advanced. The principle announced by Mosely, before referred to, shows that the atomic weights only approximate the periodic system and therefore that the true and exact periodic character of the elements is based upon the X-ray spectra.

The discovery of the electron and the X-rays gave to physical chemistry the prospect of becoming an exact science

and opened the way to a closer contact with the problem of the nature of matter than had even been conceived.

RADIOACTIVITY

Not long after the discovery of the X-rays, Becquerel, a French physicist, conceived the idea that there might be some relation between the fluorescence produced by the cathode rays and the natural phosphorescence of certain well-known substances, though he found that they were not the same. But his investigations resulted in the discovery of the radioactivity of uranium, which has a radiation in some respects similar to the X-rays and in others quite different. He then suggested to M. and Mme. Curie the possibilities of investigating the uranium ores. They took up the work with zeal and skill and soon found some of these ores were more active than uranium itself. Obviously, therefore, there was some substance more intensely radioactive than uranium. The particular substance selected for analysis was pitchblende, a highly complex mineral containing many elements, found in but few and widely separated regions. After one of the most complicated separations known to chemistry several new radioactive elements were found, notably radium, which has proven of greater public interest than the X-rays and of more importance to science. While it was easy to trace during the entire process, as its presence could always be detected by the electroscope, the difficulty in isolating it may be inferred from the fact that a ton of pitchblende yielded only a few milligrams of radium bromide.

Notwithstanding radium is a result of successive disintegrations of uranium and a series of its products and is itself in a state of constant disintegration, it is regarded as an element. It has a perfectly definite spectrum and an atomic weight of 226. It is the most concentrated form of energy within the range of human knowledge, and is a million and a half times as radioactive as the uranium whence it is derived. The source of this energy is inscrutable and inde-

pendent. The rate of its discharge cannot be hastened or retarded by any known means. Radium is self-luminous. Its radiations produce chemical reactions and decompose the most stable chemical compounds. They ionize the media through which they pass, even such dielectrics, or non-conductors, as pure liquids and such solids as paraffin. They liberate heat, and this indifferently as well at the lowest as at ordinary temperature.

All radioactivity is embraced within three distinct types, known as alpha, beta and gamma rays, named after letters of the Greek alphabet. Radium gives off all three. The determination of the nature of these rays was simplified by the precise knowledge already obtained concerning the electron and the X-rays. The alpha and beta rays are material, being particles. The gamma rays are not material, but are electrical impulses that attend the discharge of the beta rays. The alpha particle is the swiftest of any known, having a velocity about one-tenth that of light, thus manifesting an enormous kinetic energy. It affects the photographic plate and excites fluorescence. Its mass is about four times that of the hydrogen atom, and because of its size it does not penetrate matter. It carries two units of positive charge. It is the helium atom! The beta rays are electrons, and the gamma rays, which always attend the beta rays like waves of sound from the shot of a gun, are identical with the X-rays, being electrical radiations that result when electrons are violently expelled from the atoms. The gamma or X-rays are usually of two distinct wave-lengths. The secondary ones are caused by the impact of the beta rays upon the anti-cathode. Most elements give out both these characteristic wave-lengths, which form the X-ray spectrum.

The distinctively radioactive substances appear to be derived from uranium and thorium, the two heaviest and therefore most complex elements. All are unstable, else they would not be radioactive, but most of them are so unstable that they endure in distinctive forms for only brief periods. Thirty-five of these radioactive substances have

been discovered and their positions in the three main series determined. While each of these substances is regarded as a distinct chemical element, it differs from ordinary elements in the spontaneous emission of special radiations through which it is disintegrated, each in its own way, with a degree of energy vastly greater than is shown in any form of chemical reaction; and this cannot be affected or controlled by any known means.

THE CONSTITUTION OF MATTER

Science is far from arrival at final conclusions as to the significance of the phenomena here outlined and many others of a highly technical character to which investigators are directing a degree of attention far surpassing in minute precision any methods previously known. The structure of the atom now regarded as most probable is based on the "nucleus theory" of Rutherford. "A heavy atom," he says, "is undoubtedly a complex electrical system consisting of positively and negatively charged particles in rapid motion. The general evidence indicates that each atom contains at its center a massive charged nucleus or core of very small dimensions surrounded by a cluster of electrons probably in rapid motion which extend for distances from the center very great compared with the dimensions of the nucleus. Such a view affords a reasonable and simple explanation of many important facts obtained in recent years, but so far only a beginning has been made in the attack on the detailed structure of the atoms—that fundamental problem which lies at the basis of physics and chemistry."

The position and the character of the motion of the electrons within the atom is now the chief subject of investigation, with the prospect of final demonstration that will account for all the phenomena as yet obscure.

Potassium and rubidium are slightly radioactive, and it may be that as methods and measurements are perfected this property will be found characteristic of other elements. If all the elements are subject to disintegration through

this or other causes, they must have been formed by evolution. This conception arose long before the discovery of radioactivity as a logical inference from the revelations of the spectroscope. The form of distinct matter appears to begin with the elementary gas nebulium, the presence of which in certain nebulæ is shown by its spectral lines. Helium was likewise known in the same way long before it was found to exist on the earth. The other and more complex elements, as shown by their increasing atomic weights, appear in the spectra of the older stars, thus affording some evidence that the elements are evolutionary products of primordial forces, whatever they may be. For these reasons it will be seen why scientists tend more and more to the opinion that electrical forces are the things and matter in all its forms but the manifestations.

This outline of the more prominent features of chemical science at least shows the marvelous progress that has been made toward positive knowledge of the ultimate fundamentals. In the light of the present state of that knowledge and the promise of future additions to it, the barrier of the unknowable has again receded. At a very recent period the atomic theory was questioned in high quarters; but the verity of the atom is now undoubted, though it is no longer the indivisible and indestructible thing that seemed essential to its existence. It is manifestly a product and the seat of the energies that actuate the universe. In the mechanism of that minute but mighty engine may yet be found the clue to those mysteries that lie behind the most familiar phenomena. What is chemical affinity? Why do the same elements combine in different ways to produce diverse substances? Why do various radioactive elements have different atomic weights, while they cannot be distinguished otherwise? Why do certain elements of the same atomic weights show radical chemical differences? All these questions may yet find answer in the electrical structure of the atom. The secret of gravitation, the most baffling of all, may likewise be hidden in the nucleus of the atom.

The positive appears never to be associated with a mass smaller than the hydrogen atom, which, therefore, in a neutral state holds but a single negative electron; yet this atom is nearly 2,000 times as heavy as the electron, which is a million million times as dense as the atom and is probably spherical in form. From these facts it will be seen what an endless scope there is for different combinations of the positive and negative forces in the atomic nuclei through the long series of the distinctive elements progressively increasing in their weights, and how readily conceivable it is that all manifestations of matter whatsoever are due to differences in the quantity and disposition of the electrical energies.[17]

Equally interesting and even more obscure is the problem of the transmission of light. There is no reason to doubt that light waves are electrical in character. There seems to be no fundamental difference between waves of light and the wireless waves of telegraphy, except that the latter are much longer and of slower vibration. The progress of knowledge as to the nature of matter has inevitably led to reconsideration and revision of the former theories concerning the physics of the ether. The subject is under profound scrutiny and gives good promise of a better understanding of the medium by which the forces of the universe are exerted. "To be living in a period," says Millikan, "which faces such a complete reconstruction of our notions as to the way in which ether waves are absorbed and emitted by matter is an inspiring prospect. The atomic and electronic worlds have revealed themselves with beautiful definiteness and wonderful consistency to the eye of the modern physicist, but their relation to the world of ether waves is still to him a profound mystery for which the coming generation has the incomparable opportunity of finding the solution."

CHAPTER V

LIFE

THE BEGINNING

FOR eons the earth was devoid of life and must again become so, from precisely opposite causes. The organic cycle is now in an advanced phase, and its future duration as indefinite as its beginning. The process of its origin is the most obscure problem of science.

The paramount fact in the history of life is its evolution. Despite the conflict of opinion in the past, the evidence is now decisive. Whenever in any branch of science a striking fact, however incomplete, has been discovered, it has led to more ample knowledge. The odds and ends of natural evidence, fragments of universal truth, discerned at different times and in many places, either fit to perfection or determine the outlines of complete ideas. The progress of science has been largely the coördination of these fragments and the bold pursuit of the logic it has prompted. In no province of investigation has this method been more fruitful and conclusive than in paleontology and its related fields.

Thus far no evidence has been found to show that chemical combinations in any circumstances spontaneously produce life. If, however, life began as the normal action of inherent properties of matter under impelling conditions of environment, which science is obliged to assume, the original forms must have been of the simplest types, so minute and delicate that physical proof of their existence could not be preserved. For many millions of years after nascent life became possible and more complex organisms developed even to a degree that might have become fossilized, the accumulated strata of later geologic ages, piled to a thickness of thousands of feet above them, would have

obliterated all traces except those of a chemical character. Most of the rocks of pre-Cambrian time now known are thus metamorphic, compressed by enormous weight and crystallized by heat.

Yet chemical proofs of life are abundant in the rocks of those remote ages. Immense deposits of graphite, manifestly the carbonaceous residue of minute plants of marine origin, are found in both the Archeozoic and the Proterozoic eras. These proofs, though indirect, are positive. The only natural means by which carbon is separated from the oxygen, with which it forms carbon dioxide, is through the agency of protoplasm and sunlight. The leaf-green (chlorophyl) of plants enables the tissues to decompose the carbon dioxide, absorbing the carbon and giving off the oxygen. When, however, dead organic material is removed, as in sediments, from contact with the air and its bacterial swarms, decomposition is arrested and the elemental carbon is retained in the deposits instead of reuniting with oxygen in the ordinary course. Such was the origin of graphite; at all events, this is the only known explanation of its presence in these ancient geologic formations, and it is in full accord with the probable conditions.

The opinion has long been held by some geologists that certain forms of limestone as well as hematite and magnetite iron-ores in the Archeozoic rocks furnish additional evidence of life at that period. It is possible that the limestone might have been formed without organic aid; but denitrifying bacteria, by taking advantage of the calcareous salts in the waters, may have been the cause. The case is somewhat stronger for organic agency in the formation of the iron-ores. They existed originally as ferrous carbonate and ferrous silicate. Their subsequent change to the ferric form implies the presence of free oxygen and this in turn suggests organic causes. These conclusions are not as yet entirely demonstrated, but the facts point quite clearly to sources of future knowledge that will abundantly fill the present gaps in the early course and character of organic evolution.

There are irresistible reasons for assuming a vast period of bacterial life prior to plant and animal forms however minute and primary. Bacteria are a necessary factor in the organic processes of nature, and must have been so from the beginning. Without bacteria both land and sea would soon be uninhabitable; hence it may be assumed that during a very long period of time both were prepared by bacterial agencies for the evolution of plant and animal organisms. Certain forms of bacteria derive their energy and nutrition directly from inorganic compounds and could have thrived as soon as air, earth and water started chemical reactions. Whatever may have been the pioneers of life, bacteria apparently occupy a position midway between them and the definite cell structure of the algæ, the earliest and simplest forms of plant life known to have existed.

THE FIRST PLANTS

It is not unlikely that early forms of algæ, as of bacteria, still survive through the lapse of more than 50,000,000 years. Such phenomena are characteristic of some other types both of plants and animals, though the vast majority have become extinct after the rise of others, which bear the unmistakable evidence of their lineage. Nor is the survival of primitive forms less notable than the fact so often demonstrated through geologic history that a species once extinct has never reappeared. Yet these facts are strong proofs of the principle of evolution. The precise conditions that attended the rise of previous types cannot in the nature of things recur. Changed environment necessarily produced different results, exterminating old forms without succession or evolving new ones through adaptation. Obviously the simplest organisms would be the least affected and would be most widely distributed; hence the new forms would originate in circumstances more or less limited or local, while elsewhere the old, without the compulsion of necessity or the stimulus of more favorable conditions, would continue unchanged. The algæ are of peculiar interest not only be-

cause of their primitive character and persistence, but of also illustrating the fundamental process of evolution which has prevailed through both kingdoms of life on the earth from the period of their origin.

The algæ were the source of the enormously diversified order of Cryptogams—plants that produce no flowers or seeds. The algæ and allied growths are technically known as Thallophytes, as they have no roots, stems or leaves. They range from single nucleated bits of protoplasm to the gigantic Macrocytis of the South Seas, including the desmids and diatoms, which have existed in inconceivable myriads during many geologic periods, and the sea-weeds that flourish in tropical waters. The minute forms abound in stagnant pools and damp soils and spread over wet stones and the bark of trees. Being the simplest of all plants, each variety is composed of only one class of cells, which draw nourishment directly from inorganic substances held in solution by the waters or surrounding moisture. The primitive forms have but a single cell. Higher forms have branched or unbranched chains, filaments or sheets of cells, while the still more complex types bear a close resemblance, in appearance rather than in fact, to familiar plant growths. The single-celled varieties increase by division. In some Cryptogams the process of reproduction is quite complex, being accomplished by the union of germ and sperm cells, neither of which is capable alone of further development, thus illustrating the undoubted origin of the great order of Phanerogams, the flowering and seed-bearing vegetation that appeared much later.

The fungi, with their thousands of distinct varieties, are closely related to the algæ, being parasite forms, devoid of chlorophyl and thus unable to subsist on inorganic matter. The lichens, also of many kinds, are of the same origin. They are symbiotic or consorting organisms, composed of the higher fungi in union with single-celled and threadlike algæ, one supplying the water and the other the carbon. This symbiosis (from the Greek for "life together") is

characteristic of certain of the bacteria, which it is reasonable to suppose were ancestral to the primary algæ.

The most significant feature of these different phases of primitive plant growths, and which continues through all subsequent developments, is that in whatever direction the course of evolution has taken there has been an unbroken line, one form insensibly grading into another through some slight modification or addition of function, which is always and necessarily attended by a corresponding change in physical form and character. The outstanding principle in natural history is that conditions give rise to function, and function simultaneously requires an appropriate organization for its exercise. This is the key to the evolution of life and the most mysterious attribute of nature.

THE FIRST ANIMAL ORGANISMS

The tangible evidence of the earlier forms and stages of animal life is less definite and complete than that of the primary plants. It is unknown when the Protozoa, single-celled types of animal life, first appeared; but it must have been after a long bacterial stage and possibly not until the algæ had arisen. Animal life, being chemically dependent upon bacterial and plant life, could not have existed without them. The medium of animal origin was water, probably at the start the water of moist soils containing the necessary elements brought there by erosion and combined by natural means into forms suitable for animal assimilation. The simplest Protozoa subsist on bacteria, and the more advanced on the minute algæ. Thus in the primordial conditions, after geologic and bacterial action had supplied the waters with the necessary materials and brought forth luxuriant plant life, though of small and simple kinds, the Protozoa were provided with the means of subsistence and the environment for increase and evolution.

The same general considerations as to the persistence of the earliest plant organisms and the lack of fossil proofs of their existence in the pre-Cambrian formations apply to

the primitive animal types. Before the appearance of the Metazoa (many-celled), that began to use lime and other minerals in their structures, the insubstantial remains of the previous simpler forms could scarcely resist destruction in the metamorphic rocks where the evidences might otherwise be found. Nevertheless, there are two reasons that point to an evolution essentially parallel with that of plant life. From the period where fossils show the stages of animal evolution and geologic strata record the time, that process is clearly demonstrated; hence the conclusive presumption that the prior course was governed by the same principle. Equally decisive is the complete existing chain backward to the infusoria, the amœbæ and the monera, the latter being little more than specks of protoplasm with no other function than to assimilate food by surrounding it and multiplying by cell division. Thus the early history of animal life is in all respects analogous to that of plant life, showing a similar gradual increase of function and complexity of organization. The changes radiated in many directions and resulted in thousands of forms that finally lost all resemblance to one another and require the eye of an expert to trace their relationship.

THE INVERTEBRATE ORDERS

The earliest geological evidence of animal life has thus far been found only in the late Proterozoic. It is not only scanty but indicates types much later than the original Protozoa. The Radiolaria, advanced forms of that order, minute but inclosed in durable tests of solica, were then in existence; also the Annelida, composed of ringed segments like the common earthworm, left their trails and burrows in the sediments of that time. These are proofs that the invertebrate classes were already well established and the sources organized for that diversity of form and function which renders the Paleozoic era the most graphic in the whole panorama of natural history.

The most notable feature of the Cambrian strata is the

abrupt appearance of fossils in abundance and variety and in advanced stages of evolution. There is manifestly an immense loss of the previous record, to a great extent, presumably, by erosion during a long period of the late Proterozoic. From all countries at least a thousand Cambrian species are known, about half of them North American. Of these the most important and the most numerous were the trilobites. They became extinct before the close of the Paleozoic; but during their long career some two thousand kinds appeared. They were doubtless exterminated because their armature, though of a horny substance, which has preserved the fossils, could no longer protect them after the alert and voracious fishes appeared, about the time when the trilobites attained their greatest development in size and numbers.

It is assumed from their structure that they evolved from wormlike ancestors. Their bodies were made up of segments articulated in three divisions. They usually had compound eyes and breathed, so to speak, through their biramous limbs by means of long hair-like appendages in which the circulating blood drew oxygen from the waters in which they lived. They were able to swim freely and to crawl and burrow along the bottom, the scavengers of their time. They multiplied sexually and during growth repeatedly cast off their shells. The peculiar interest attaching to them is due to the fact that they and their progenitors are the sources of the entire phylum of the Arthropoda (joint-footed), with articulated or segmented bodies and limbs. It includes so diversified an array as the scorpions, crustaceans, centipedes, insects and mites, which later on branched into the multifarious life of the planet.

Another of the great phyla already well established at the beginning of the Cambrian was that of the Mollusca. The forms then extinct were ancestral to the many species that appeared through subsequent ages. The most complex order, the Cephalopoda (head-footed), embracing such varieties as the nautilus, octopus, cuttlefish and squid, began the record of their evolution during this period. Likewise the Gas-

tropoda (stomach-footed), such as limpets, drills, periwinkles, whelks, conchs and snails, and the Pelecypoda (hatchet-footed), comprising oysters, clams, muscles, cockels, scallops and all their numerous relatives, were present in small and primitive forms, so that their history is graphically written with their shells through subsequent geologic strata.

Of even greater importance to geology than any of these higher types of the invertebrates are the Brachiopoda (arm-footed), a lower class of shelled animals than the molluscs, which they externally resemble, though of different origin and internal structure. The term applied to these molluscoids is a misnomer. It was early adopted through misapprehension as to the use of the brachia or arms, not for movement, but to obtain food and oxygen. The shells of this phylum are strewn in such profusion and variety through the Paleozoic and later that they have served, like the trilobites, as an invaluable index for the correlation of the strata. At the beginning of the Cambrian they existed in great numbers but few forms, the variety gradually increasing and the shapes slightly changing with time and conditions. The original species were mostly Inarticulates, the shells enclosing them not being hinged; and they became the more general type at later periods. Over two thousand kinds have been found in North America belonging to the Paleozoic; and over one hundred and fifty characteristic forms exist at the present day, the shells of many of them being familiar objects in the sands of the seashore.

It will here suffice merely to allude to other and lesser phyla—the Echinodermata (spiny-skinned), such as star-fishes, sea-urchins, sea-cucumbers and sea-lilies; and the Cœlenterata (hollow intestined), such as hydroids, jelly-fishes and the coral-polyps. They, like a great variety of wormlike types and sponges, are represented in the Cambrian by primitive forms. They afterwards differentiated into more complex classes, which ultimately became extinct or graduated into persistent forms more or less changed in detail, but retaining their distinctive features.

The chief significance of these facts lies in the circumstance that all of the great phyla or general types of animal life below the vertebrates had attained their permanent divisions and characteristics at the time when paleontology supplies the first evidence. This advanced degree of evolution justifies the conclusion that geology gives only the later chapters of natural history, and that the time required for organic life to reach the diversified and established phases revealed by the Cambrian must have been quite as long as that which has since elapsed.

When we consider how small a proportion of the life extant at any time leaves fossils even under the most favorable conditions, we may readily conceive how numerous were the creatures that teemed in the waters of the Cambrian. Animal life was yet limited to the water; and judging by those types, it is not possible that land species could then have existed. Discoveries in recent years, particularly in regions of western North America, which were submerged before and during the early Paleozoic, aid the expectation that knowledge of life in the pre-Cambrian will be greatly enlarged; and no scientist doubts that the results will be in perfect harmony with the principles of evolution manifest during all subsequent time.

The duration of the Cambrian is usually estimated at some 3,000,000 years and of the combined Ordovician and Silurian, 6,000,000 years. The physical limits of these periods are defined clearly enough; but naturally the rise and fall of species do not accord with geological divisions. The processes of evolution are by infinitesimal changes in structure through the unknown factor of life that enables the organism and its successors to adapt themselves to the environment. The changes have therefore been so slow and gradual that enormous lapses of time have intervened between the distinct phases of development which have created the diversity of species now arranged in the classified order of their fossils in the great museums of the world.

So far as now known there is not a living thing upon the

earth at the present time but has a geneology running back to the dawn of life in the Archeozoic; yet the pedigree is not decipherable when the lines of descent merge into the primitive sources. Nevertheless, the underlying principles which have governed the phenomena of life are clearly shown by the more salient facts that stand out in strong relief like great events in human history.

The Ordovician and Silurian, unlike the ensuing period, were characterized by gradual transition rather than revolution in biological development. The invertebrate types were approaching that stage when evolution seems powerless to proceed further in certain directions except to increase the size or change the detail of the most advanced species. Some orders multiplied in variety and numbers and reached the acme of their activity, as shown by the vast and diversified coral and limestone formations of that time. Others, having attained their climax, were waning toward extinction. Some idea of the general character of the mid-Paleozoic may be gained from the fact that the Ordovician has yielded five times as many forms as the Cambrian; and a similar ratio of growing diversity marks the Silurian as compared with the Ordovician.

THE FIRST VERTEBRATES

Out of this increasing welter of biologic detail two great and prophetic facts arrest attention. It has always been at such stages that new departures have been made. It was evidently then that the ancestors of the invertebrate terrestrial hosts emerged from the waters and started that ramification of orders and species which were eventually to invade the land with swarming myriads in an infinitude of forms. Moreover, it was then that the vertebrates made their appearance, small in size, simple in structure and few in numbers. The two facts that justify this conclusion are the presence of scorpions, the first known air-breathing creatures, and the fossils of the first known fishes.

At the close of the Devonian the life of the world had

assumed a new aspect. On the land as well as in the waters, plant and animal life, from lowly beginnings and through tortuous progress, had at length amassed from the sun and elements such a store of vital energies for reproduction and sustenance that organic development was greatly accelerated. The Devonian earth had not only inherited the accumulated results, but multiplied their potentialities. Thus time and circumstance had invested this period with characteristics that render it, if not the most important, at least the most decisive in organic history. In a general sense, the future of species was then determined. The back-bone and the lungs were established, and the trend of evolution fixed in necessary accord with the general planetary conditions.

Whatever may have been the original vertebrates, the fishes were the first to develop the spinal structure with permanent success. The actual course of their evolution is still undiscovered; but the probable stages are quite clearly deduced from existing types of fishlike creatures with incipient vertebræ. It is assumed from the nature of the first fossils and the localities where they were found that the fishes originated in inland waters and afterward spread to the seas, rapidly becoming the dominant life. The chief reason for the absence of fossil proofs of the antecedents of the known fishes is that the original forms were very small and without hard parts. None of the many species from the Devonian had a bony vertebral structure. Even the sharks, then as now, were without bones except their teeth and the spines in their fins, which thus furnish evidence of their ancient origin. They are the most primitive of all true fishes at the present time, not only because of this, but of their archaic organs, notably the gill-slits in the throat.

As there were several distinct classes early in the career of the fishes it is possible that they originated independently. The oldest of these—the Ostracoderms (bony-skinned), heavily armored and sluggish, without a skeleton, but with a gristly spinal column of a simple kind—wholly dis-

appeared before the close of the Devonian. Yet they must represent a relatively late stage in the scale of vertebral evolution from probable pro-fish forms in the Cambrian or earlier of which no fossil traces remain.

Among all the groups common in the Devonian, but now extinct or represented by modified descendants, the most important in scientific interest are the Dipnoi (double-breathing) or lung fishes. Species of these still survive in the rivers and marshes of Australia, Africa and South America. The original stock that produced them and the fringe-finned ganoids are regarded as the source from which the amphibians and through them the reptiles and mammals have been derived. But here, as in so many other instances of the rise of new orders, the precise link is missing between the first known air-breathing fishes and the stock below from which they branched in one direction and the amphibious salamanders in another. This is expectantly sought in the Devonian and may yet be found even in the Silurian. The distinction of the lung-fishes is the double office of the air-bladder, which serves in times of drought as an organ of respiration in place of the gills. It returns the aerated blood directly to the heart and is therefore analogous to the lungs of the higher vertebrates, unlike the systems of most other fishes, in which the blood is carried from the bladder through the circulation before reaching the heart. It is a forward out-growth of the digestive tract and doubtless arose from the conditions of feeding and breathing in shallow waters where the original stock evidently appeared.

THE FIRST VEGETATION

The fossil indications of land plants during the Devonian are scanty but suggestive. It is certain from the great luxuriance of the Carboniferous, or Pennsylvanian, that in the Devonian and perhaps in the late Silurian many lands were decked with verdure, and forests truly primeval flourished

in many regions. The giant forms and enormous masses of vegetation that entered into the Coal Measures point to a long interval of probation and development before the original minute and delicate land flora, as the earliest must have been, could have reached such an advanced stage; for it was not until the upper Devonian that any plants acquired the woody tissue necessary to preserve them as coal or fossils. As the coal floras, which are the sources of most of the present knowledge of the primitive land plants, include some three thousand species, botanical science is confronted at the very threshold with a degree of complexity and diversity that still present intricate problems of origin and heredity. However, a mere outline of the more important plant forms of that period will give some idea of the forests that choked the swamps where the future coal mines of the world were laid.

The majority of the plants then existing were propagated by spores, which in the larger varieties were shed from cones in great numbers and scattered widely by the winds. They united and took root in profusion in the rich, moist soil; and their rapid growth was continuous owing to the genial climate that prevailed over most of the earth and throughout the year. The seed-bearing plants were in their youthful stages, while the flowering types were yet in their infancy. The largest and most abundant growths were the Lycopods (wolf's foot, from the form of the roots), of which there were more than two hundred species, the most common being the "scale trees" and the "seal trees." They often reached a height of over a hundred feet, with corresponding girth. The wood was soft and spongy, inclosing a pithy interior. The scale trees, which in type were giant club-mosses, forked at a considerable distance from the roots and bore long, thickly set, needle-shaped leaves that dropped from the trunk and the older branches. The leaf bases thus exposed were arranged symmetrically and resembled scales. The seal trees were not usually as tall as the scale trees, but stockier with few or no branches

and with stiff, grasslike leaves of greater size. The older leaves were shed in the same way as those of the scale trees, but the leaf bases were of other shapes and arrangement, thus presenting a different appearance. The seal trees died out toward the close of the Carboniferous, leaving no descendants; but the scale trees are still represented by such diminutive forms as the trailing club-mosses and the ground pines.

Another varied group known as the Horsetails were common at that period. The larger ones attained a height of ninety feet, the slender stems or trunks being of a pointed and rushlike form, hollow or filled with pith, and putting out leaves of different shapes arranged in whorls around the joints. The ferns were abundant and many of species, ranging from small plants to huge tree-ferns, resembling those now found in the tropics. The modern types, however, were a later evolution from the early stocks. There were also numerous species of seed-ferns, which soon became extinct, being transitional to higher groups. Equally important in the flora of the Carboniferous were the Cordaites, named after Corda, an eminent paleobotanist. They were the dominant Gymnosperms (naked seed) of the Paleozoic and numbered many species. They reached great heights, some having huge, strap-shaped leaves that grew from branches well toward the tops, and bore small male and female flowers that developed seed clothed with husks. This group appears to have been a composite of several features of the great orders of that time in which modern botany finds the origin of the vegetation so enormously diversified and adapted to the varied geographic and climatic conditions. But none of the Angiosperms (covered seed), the great phylum which now embraces most of the vegetation of the world—grasses, cereals, bamboos, palms, orchids, forest trees and flowering plants generally—had yet appeared.

This remarkable development of plant life was accompanied by similar phenomena of animal life. The closing

periods of the Paleozoic Age were equally significant in both phases of organic evolution; and the coal deposits have furnished the principal records of both, which, for like reasons, are much less complete in the earlier stages than after the conditions of the Carboniferous became so perfectly suited to the preservation of fossil history.

INSECTS

The thousand or more species of insects from the Pennsylvanian and Permian are all supposed to have arisen from a primitive type derived from the trilobites. All the known early forms passed their larval stage in the water. While there are few indications of insects until the Pennsylvanian, there can be little doubt that the great development and different forms which then existed must have been preceded by a long period of evolution. The direct line of the primary type, the first dragon-flies, attained great size. Specimens have been found measuring twenty-nine inches across the wings. Among the existing old families the cockroaches hold a distinguished position. More than five hundred kinds have been found in the Carboniferous of various lands, some of them three or four inches in length. The grasshoppers have a lineage almost as ancient, and the spiders even longer, but they had not yet begun to spin.

As numerous as the insect species were then, they were few as compared with the many hundreds of thousands which have since flourished in the many unlike regions of the world. The chief cause of this later multiplicity was the great diversity of environment that began in the Permian because of the increasing cold and aridity and the inception of climatic zones and seasonal changes. From these conditions arose many new orders that lost their amphibious character, developing the modes of reproduction and metamorphosis that now prevail, with intervening dormant periods brought about by cold weather and the lack of food.

THE AMPHIBIANS

Nor was this variable factor of heat and cold less decisive in its effects upon other classes of animal life. The amphibians, which in the highly favorable circumstances of the time, reached the climax of their evolution in the lower Permian, were markedly affected by these changes. Their stocks were able to adapt themselves to the new conditions and continued to advance through the reptiles toward the mammalians, while the more highly organized were powerless to change and were therefore doomed to extinction—a phase and a proof of evolution often witnessed throughout the history of plant and animal life.

The only evidence now known of amphibians in the Devonian is a single foot-print indicating a creature somewhat like a salamander about three feet in length. From the lower Carboniferous, or Mississippian, the proofs are sparse; but that the amphibians were present in ever increasing number and variety is apparent from their rapid progress afterward. During the lower Permian the general conditions were so much like those of the Pennsylvanian that animal life was not materially affected. Gradual changes are observable in many directions, but the most notable feature was the rise of the reptiles, which began very soon after the amphibians appeared. This transition was through such slight differences that in some cases it can scarcely be determined where one order ceases and the other begins. Nowhere in natural history is the principle of evolution more clear and conclusive than in the fourfold progression from air-breathing fishes to the amphibians, from amphibians to reptiles, and later from reptiles to birds by one route and to mammals by another.

VARIABLE CLIMATES

It will be recalled that there are some indications of local glaciations in the late Proterozoic Age. These instances may be reasonably explained by regional elevations through internal disturbances, and thus afford very good evidence

that the normal temperature relations of the sun and the earth at that period were not radically different from those of later times. The glaciation in the Permian, however, appears to have been of another character. In the Pleistocence the ice-sheets were apparently more extensive in the northern latitudes, though not absent from the southern. In the Permian they appear to have been greater in the southern than in the northern hemisphere. More complete knowledge of the geology of these periods may show that these latitudinal differences were not so pronounced as hitherto supposed.

If geology were without physical evidences of the changes in temperature, the fossil proofs and formations of organic origin would suffice. Thus it is known that during the entire Paleozoic and until the mid-Permian the climate of the earth to within ten degrees of the poles was mild and equable. The corals and limestones of the Cambrian, Ordovician and Silurian could not have been laid had the oceanic waters, north and south, been as cold as those of the temperate zones in the present age. That these conditions were not interrupted in the Devonian and Carboniferous is confirmed by the vegetation. The land flora during the long course of its development before the Permian is fitly described as cosmopolitan, being composed of species common the world over. And this token of uniform climate is confirmed by the structure of the wood: it was continuous and not made up of annual concentric layers, each the product of a season of growth followed by a season of repose.

The cause of this constant and general climate has been the subject of as much speculation as the cause of the ice-sheets and with no more certain result. The solution, however, has been aided by the abandonment of early theories advanced when the nature of the sun and its energies were much less understood. The physical logic would seem to point to a difference in the sun's radiation. The persistence of its great heat through geologic time, so long a mystery to science, is probably explained by the radioactive elements

in its mass. Yet there must have been some decrease, and the glacial epochs may well have been due to the accumulated effects of this expenditure, at length producing some degree of external obstruction. The warm interludes characteristic of both glacial periods are consistent with renewed outbursts of energy until equilibrium was finally established for another long ensuing stage, but with a somewhat reduced temperature. Coupled with this primary cause of climate was the probable change in the currents of the air and the oceans. Certain it is that in the early Permian culminated in various parts of the world a series of mountainous upheavals and vast changes in the areas of the lands submerged. These new conformations must have profoundly affected the prevailing winds and oceanic streams.

The consequences are first seen in South America and Europe, where the cosmopolitan flora vanished and new types appeared. In North America the conditions were somewhat different, but the changes were not less notable, owing largely to the arid or semi-arid climates that prevailed over most of the earth. Geologic time records no greater contrast in the character of the life of two successive periods than is revealed by the Permian and Triassic. Evolution had progressed so far and gained such momentum that changed conditions brought immediate and signal response. Although the Mesozoic Age was only half as long as the Paleozoic the evolution of life was far more rapid, vigorous and varied; and these characteristics are conspicuous in the Triassic, with which the Mesozoic, the Age of Reptiles, opened.

THE RISE OF MODERN TYPES OF VEGETATION

The forests were soon transformed. All the more important spore-bearing plants had gone, and the ancient ferns were merging into the modern stocks. The older seed-bearing plants had given rise to the conifers, from which the numerous family of evergreens have sprung. The Cycads,

which were the ancestors of the great palm group, abounded in many regions. The forests, however, were not as extensive nor the trees so large as during the Carboniferous, except in favorable locations where the soil was well watered. In such places specimens have been found much larger than any from previous time. The uplands were not so well clothed, the vegetation there being of types adapted to the more arid conditions. In the swamps and moist lowlands the modified descendants of the Horsetails were the most abundant of the smaller plants.

In the upper Triassic and during the Jurassic the climate again was warm. Marked seasonal changes had not yet been established except in extreme latitudes. The effective lowering of the temperature was in the polar regions and the waters. Thus in the Jurassic some kinds of vegetation became quite cosmopolitan. The floras of the world show no great changes, but a steady and gradual transition toward the modern types. This tendency becomes more clearly defined in the late Cretaceous, the close of the Mesozoic age. By this time the flowering plants, which had long been in their initial stages, were in the ascendant. Most of the now familiar woods of the temperate zones had taken the place of the former types, first appearing in the far north and thence spreading toward the interior latitudes with the moderation of the climate. Of decisive import to the course of mammal evolution, as yet only in its first stage, was the appearance of the sedges and grasses. With the physical logic so obvious throughout the entire course of evolution, when the flowers appeared the bees came also, beginning those mutual relations which have ever since continued with such beautiful effect upon the floras of the earth. The coloring of the flowers, however, must be sought in some other cause than the preference of bees and other insects, as was long supposed. These creatures are color-blind. To them all colors appear as shades of gray. Chemical reasons, through the property of absorbing only certain rays from the sun, are the probable explanation of floral hues,

without detracting from the aid of the bees in fertilization and diversity.

CHANGES OF VERTEBRATE LIFE

The development of animal life in some directions was so varied and so radical that a general outline will afford a better idea of its essential features than any attempt to group the details. In this era the marine invertebrates reached their climax. Many species became extinct, mainly because of the gradual cooling of the waters and the increase of superior foes. Others less complex were able to adapt themselves to the changing conditions, and their successors persist through variation. As the rise and fall of shelled genera serve the double purpose of illustrating their evolution and accurately marking the time, they have gained a prominence in both geology and biology more conspicuous than intrinsically important. From a practical point of view, the advent in the Jurassic of oysters and claims, lobsters and crabs, is the most satisfying evidence of evolution among the many kinds of invertebrate life.

The transition of vertebrate forms was naturally far less rapid and striking in the water than on the land. During the Mesozoic the principal fishes of the preceding age continued, with some modifications and some change in their relative numbers. The sharks were still numerous, but less so than the ganoids, so called from their enameled and shining appearance. This great order originated early in fresh waters, but eventually gained predominance in the seas, which they held until the rise of the teleosts, or bony types, now comprising ninety-nine per cent. of all the fishes in the world. The teleosts appeared toward the close of the Paleozoic, afterward increasing steadily in number and variety, while the ganoids became correspondingly fewer. Of this ancient type only such species as the sturgeon and gar-pike remain. It was from the ganoid stock that the teleosts were derived. Because of this fact and the probability that from the ancestors of the ganoids the amphib-

ians had their origin, this great group holds an eminent position in the line of vertebrate evolution.

THE AGE OF REPTILES

The rise of the mammals from the reptiles, with all that implies, is not a more wonderful exhibit of the process of adaptation than that displayed by the evolution of the reptiles from such an unpromising source. Thus in a peculiarly suitable environment the first of the amphibians increased their power to breathe the air. Meanwhile through successive generations the fringe-fins were transformed into limbs and feet to aid in performing the new functions necessary to existence in new surroundings. With this start the subsequent changes were inevitable. The number of futile experiments made by nature to create the line that was to produce the primate mammals may be guessed from the many orders of amphibians and yet greater number of reptilian types, most of which are now extinct and the others hardly more than reminiscent of the period of their greatest development. The process was long and devious. From the first appearance of the fishlike creatures that led the way to the highly complex and gigantic monsters that marked the acme of reptile evolution nearly 20,000,000 years elapsed.

During the Reptilian Era of about 12,000,000 years eighteen great orders, each with many species, were evolved. Of these but five remain: the tuateras, a single form confined to New Zealand, the turtles, crocodiles, lizards and snakes, all in many forms. The snakes were the last to appear. They originated from a type which had lost its limbs; the diversity of species did not arise until much later. The other orders disappeared during the close of the Mesozoic. The almost abrupt extinction of such vast numbers in so many varieties, land and aquatic, from the very small to the largest creatures that ever inhabited the earth, is one of the mysteries of organic history. Extensive draining of the great inland seas during the late Cretaceous was

doubtless an important factor, involving prohibitive changes of habitat and the destruction of the normal food supply. The plant-eating species may have fallen prey to the carnivorous. The eggs and young of both may have been devoured by the mammals that now began to multiply. Although the new-comers were yet small, they were equally voracious and vastly more alert and efficient in body and brain. Such are some of the explanations which have been advanced. The most probable cause was disease.[18] The reptiles had passed their physical climax and may have become subject to some world-wide epidemic such as destroyed whole orders of mammals over entire continents in later times.

At this period the potential limits of evolution become apparent. Long before the intermediate forms of land vertebrates reached their culmination in the reptiles the marine invertebrates had passed through all the stages of their transition, and the surviving forms remain essentially the same as they were then. The marine vertebrates had a shorter course of development before the rise of the bony fishes, which mark the limit of their possibilities; for their subsequent evolution has been only in detail of form and fitness. The amphibians were only a passing phase, and their distinctive career was correspondingly short. Such as still survive are but humble reminders of a bygone stage, provisional in its nature and inevitably merged in a higher development. The era of reptiles reveals similar characteristics, yet in a magnified degree. These uncouth creatures inherited the latent attributes of their amphibian ancestors and extended the inheritance in many directions until they also exhausted the physical power to proceed further, except by new and higher types of evolution moving through forms which had not become so specialized as to resist the change.

The greater diversity of reptiles than of previous orders was due to the variety of conditions to which they could become adapted through increased flexibility of type. From probable lizard-like forms that may have originated in the

Carboniferous the several great divisions arose and branched many ways. One or more of these divisions took entirely to the water, where they developed aquatic forms, some like fishes and others like serpents. Several varieties attained prodigious size and met the same fate that befell their congeners of the land. Another division acquired very considerable powers of flight. From small bat-like creatures were evolved a numerous group of different shapes and characteristics, some being carnivorous and armed with formidable claws and teeth. Like birds, they had light skeletons with hollow bones. Specimens have been found with an enormous spread of wing, which enabled them to soar far over the shallow seas for prey of no small proportions. These flying reptiles were the most extraordinary of all extinct animals; and curiously enough it was not from any of this group that birds were derived, but from an early branch of the original stem that produced the great order of the dinosaurs (terrible lizards).

The earliest known bird is the *Archeopteryx macrura*, the imposing equivalent for "long-tailed primitive bird-creature." It was found in the Jurassic of Bavaria. The appearance of so highly developed a species in that early period shows that its lineage was as old as that of the flying reptiles, having diverged from the original reptile stock quite as soon and with a more promising future. Its reptile origin is unmistakable. Although with the legs, claws, feathered wings and general form of a bird, it retained several characteristics of the reptile. Claws extended from the second joint of the wings; the tail was a continuation of a long spinal column, at each joint of which was a pair of steering feathers, one on either side; and the jaws of the bony beak were well provided with teeth. There must have been a long series of intermediates of which no trace has yet been found. Even the long sequence from the *Archeopteryx* to the next known bird fossils, from the Cretaceous, is entirely missing. Some thirty species of that period have been found in Kansas. They belong to two groups, one com-

posed of large water-fowl, some of them unable to fly, and the other of smaller ternlike birds also of aquatic habit. They show a distinct advance, though still bearing in their toothed jaws and other features the evidence of their reptile origin. Enough, however, is known to show that the varied evolution of later orders was well under way; and soon afterward, in the Tertiary, they attained the true characters of the modern birds.

The precise mode in which the power of flight was developed is yet the subject of debate among naturalists. The weight of the argument is probably with the theory that the beginning was batlike, all four limbs being used and all becoming more or less feathered. Physical necessity led to the evolution of the wings from the fore legs, which was aided by the original bipedal form of the species. The efforts exerted in attaining flight not only brought about the peculiar structure of the bones, but improved the circulation of the blood, which thus became warm, unlike that of reptiles generally.

Were not the facts so well known from the abundance of fossils, which are yearly accumulating in the museums of the world, the weird variety of species and the magnitude of form attained by some of them would be incredible. Unaided imagination could scarcely have conceived the uncouth shapes that inhabited the strange world of the Mesozoic. That great era of riotous growth in animal life, without other result in the climax than to produce the gigantic and the grotesque, is from a scientific point of view little more than an episode in which the possibilities of evolution in favorable conditions were carried to extremes. Lacking elements of further adaptation to a changing world, most of these creatures passed into extinction, only leaving here and there a mighty reminder of a racial existence doomed from the beginning.

The most significant fact of all this development of sheer physique is its independence of mind. No quadrupeds have ever lived upon the earth in which the brain has borne so

small a proportion to the bulk of the animal. The great reptiles were mainly organized appetite, "complex mechanisms for the capture, storage and release of energy" without a nervous system of acute sensibility; yet physically they have never been equalled. "As pure mechanisms," says Osborn, "the cold-blooded reptiles exhibit as great plasticity, as great diversity and perhaps higher stages of perfection than the mammals. Nor does increasing intelligence favor mechanical perfection."

Most of the reptilian orders were oviparous, producing their young externally by depositing eggs which hatched without further care. Others were viviparous, producing their young internally. Both modes have survived in the reptiles of the present. The viviparous types appeared later than the birds, which have therefore retained their early character in this respect; and it has been peculiarly suited to their entire evolution, though their vascular system was entirely transformed.

The protracted time covered by the evolution of the reptiles from their amphibious origin is well illustrated by their eggs, which are invariably laid on the land; and the young, whatever may be the habit of the species, are air-breathing, while the amphibians always begin life in the water, breathing like the fishes by means of gills, which are soon lost and their office replaced by lungs. Thus the development of the tadpole rehearses within a few days the process of millions of years required for the transition from fishes to frogs.

The evolution of the reptiles is similarly shown, though in a less distinct way, as with all high orders, by the embryo. The shelled egg, with the peculiar membranes that develop as incubation proceeds, to protect the embryo and provide for respiration, was as necessary to the first reptiles as their physical characteristics and was evolved at the same time through the same causes. The original stock was confined to the land and without doubt arose by reason of the arid conditions when they first appeared. The aquatic reptiles were a reversed evolution, appearing later through changes

in the habitat, but retaining their original character—the inflexible rule with every order in which such a reversion has taken place.

The change of the tadpole and the hatching of the chick have been of far-reaching import in the development of thought. They suggested and sustained the idea of evolution long before it was accepted by science. Some discerning minds saw in such phenomena sections of orderly growth from phase to phase and conceived, dimly but with assurance, that the organic world is a development. This was the solitary beam that shone through the long night of superstition, the source of the worst evils that have beset the race. The science of embryology had a homely beginning, but it has been a potent factor of progress.

THE RISE OF THE MAMMALS

That the beginning of the most radical divergencies are usually the most obscure is again illustrated in the origin of the mammals. Such departures have been made only through a long series of minute changes during a long lapse of time; and since only a very small proportion of any series has been preserved the entire process from stage to stage must be deduced from fragmentary evidence of several kinds. It was long supposed that the original stock of the mammals branched directly from an amphibian because of certain peculiarities of anatomy; but the natural zeal of research to establish the true line of our own ancestory has made it clear that the pro-mammal was reptile.[19] The most important break in the line was finally closed by the discovery in the Triassic of Africa of fossil reptiles known as the cynodonts, because of their doglike teeth, which are distinctly incisors, canines and molars. While the structure of the head shows other mammal resemblances, the essential character of the order as reptiles is undoubted. This course of descent is confirmed by two distinct types of existing animals that illustrate intermediate stages of mammal evolution; the monotremes of Australia and New Guinea, the last survivals of a

primitive egg-laying stock; and the marsupials, pouched animals such as the kangaroo and the opossum, which bring forth their young in an embryotic condition.

The limbs of the African pro-mammals were also in an advanced stage of evolution, which enabled them to travel with ease and speed impossible to other reptiles. The power to migrate, associated with teeth adapted to different kinds of food, would indicate the greater degree of intelligence to be expected in the type representing the stock from which the ultimate evolution of form and brain proceeded. A wider range of habitat and food implies a greater power of observation and choice. It is from this cause that the whole history of the mammals is marked by specialized tooth structure, in contrast with that of the reptiles generally, in which tooth development ceased.

It is not evident that there was any relation between the disappearance of the great reptiles and the rise of the mammals. The mammals doubtless originated long in advance of the geologic strata in which their fossils are first found. That epoch was probably the Permian, mainly because of the climatic conditions. The cold and subsequent aridity forced animals to migrate or die. This travel in search of food in a different region improved leg development and increased activity. This in turn, through rising bodily temperature, transformed the cold-blooded reptile into the warm-blooded mammal. The change was attended by the development of the four-chambered heart and the complete separation of the arterial and venous circulation of the blood, and the increase of the temperature of the blood favored the evolution of a higher nervous system. Change of habit and physique tended to produce the placental mode of bearing the young characteristic of all the higher mammals. Changes of external temperature through emigration or seasonal causes tended to produce a protective covering. The birds gained feathers; and the mammals, hair. In such circumstances the animals that acquired these characteristics had the advantage; those which could not,

because too highly specialized, were in peril of elimination. Such is the rationale of mammal evolution.

That the mammals, once started, spread with notable rapidity is shown by the late Cretaceous in many different regions of the earth. These fossils are composed almost entirely of lower jaws, which, however, are the most significant part of the skeleton. They show that at the close of the Mesozoic the mammals were yet very small and of the most primitive types. Probably none of them were more than a few inches in length. That they were already diversified is apparent from their teeth, which were adapted in each species to the particular class of food it required. This fact may well account for the exceptional variety and repidity of their evolution during the Tertiary, which now opened. Each type would thrive best where its peculiar food was most abundant, and, with great ease of movement, would seek it. Migration would lead to new habitats where the conditions, though favorable, were different. Moreover, the mammals could more readily adapt themselves to circumstances than any of the orders which had previously existed, and their young were better protected. In such new situations there would be a tendency to evolution of form and character. These considerations are rather obvious, but they exhibit the factors of what the biologists are wont to describe as adaptive radiation.

MAMMAL EVOLUTION

In a sketch of origins the marvelous detail of the last phase of animal forms may only be broached. Upon this great subject some of the ablest minds of science have bestowed their chief labors, and many of the successions have been worked out with a degree of completeness and certainty that leave no problem as to the course of descent. The evolution of the elephant, the camel and the horse, not to speak of other types, as seen in the series of their skeletons, is so apparent that intelligent doubt is no longer possible. The sequences thus established are so many and

so conclusive that they bridge every gap in every line of descent with the logical implication of a similar gradual development. One of the most suggestive episodes in the history of thought is that at the time President Noah Porter of Yale was thundering against the principle of evolution, Professor Marsh, of the same college, was perfecting the now famous collection of skeletons, showing a complete series of forms beginning with a five-toed animal no longer than a fox from the Eocene and ending with a hoofed horse of the Pliocene.

The duration of the Tertiary is generally estimated at about 3,000,000 years, divided among its four epochs—Eocene, Oligocene, Miocene and Pliocene. Of these the first is perhaps of most interest as being the evolutionary stage when the immediate ancestors of the modern mammals appeared. The initial stage, during most of the Mesozoic, brought the mammals into being and laid the foundation for their future possibilities. This foundation was broad, and the possibilities included man. So well adapted were these orders to the conditions that were to endure for a long future that the divergence of the species progressed with greater speed than during any other period of organic evolution. And it is to be observed that the advent of the modern forms of animal life was long preceded by the climax of plant life. At no stage in the history of vegetation has its luxuriance and diversity been greater than during the close of the Mesozoic, when practically all of the present forms as well as many now extinct had reached their full development.

Before the close of the Eocene the secondary and archaic types of the mammals began to die out and the more modern to take their place. This process is yet more striking in the Oligocene. Wherever the origin of the new types may have been, the phenomena of their diffusion is abundantly recorded. During some epochs there was a very general dispersion of the land faunas of the several continents, with the exception of Australia, which was permanently severed

from Asia before the Eocene. At other periods whole orders dwindled away in one continent, while persisting in more or less modified forms in another. The land connection between Asia and North America and between North and South America was inevitably followed by the intermigration of the various faunas; and the severance of those continents invariably resulted in separate trends of evolution. This unity of North America, Europe and Asia prevailed during the Miocene and the Pliocene. Toward the close of the Pliocene communication between North and South America, which had been interrupted for more than a million years, was again restored. Thus the community of the mammalian life of most of the lands attained its greatest epoch in the early Pleistocene, just before the Ice Age.

The vast importance of migration as a factor in animal evolution is aptly shown by the faunas of Africa and Australia. During the immensity of time covered by the development of vertebrate history a great part of Africa was exceptionally stable and in unbroken connection with Asia, which is supposed to have been the chief birthplace of the mammalian orders. It was also exempt from the ice sheets of the Pleistocene, which extinguished all life within their frigid advances. These circumstances have made Africa a more complete repository of faunal history than any other continent; yet there investigation has only begun. On the other hand, Australia, left to itself during the major part of mammal evolution, contained only the types which had evolved at the time of its isolation. When in modern times the first settlers entered that virgin country, placental animals did not exist there; its mammals were entirely of the egg-laying and marsupial species. It is therefore assumed that none of the original placental stock had appeared or at least had entered Australia when it was severed from Asia, and that the other types were already too highly specialized to lose their character. Madagascar affords a lesser but significant example of the faunal effect of isolation. It became an island before the close of the Tertiary;

and the subsequent history of its animal life has been plainly controlled by local conditions.

The Age of Ice marks the boundary between the old world and the new. When at length the last glacial invasion retreated the aspects of life assumed an unwonted phase. The topography of the continents and their drainage systems were substantially the same as now. The newly established and somewhat lower equilibrium of the sun's heat had resulted in zones of temperature and seasonal changes as they now exist. The effect upon plant and animal life was decisive. The types of vegetation, which again advanced over the regions devastated by the ice, were in accord with the climates in which they grew; and the forms and distribution were essentially the same as now.

With animal life, both land and marine, the sequel is more striking. Climatic changes wrought their immediate effect upon the faunas of the various regions, which thus became the abode of types suited to the varied conditions. This soon led to that localizing of species which has ever since prevailed. Birds and insects have since continued their evolution to some extent; but with animals, to use the word in its usual sense, the process has been arrested, except as it has been carried on by artificial selection. This arrest, however, has been because the conditions have been stable during the relatively short time that nature has been under intelligent observation. How far the extinction of types that existed in great size and numbers in the early Pleistocene has been due to man, who afterward emerged as the most formidable slayer the world has produced, cannot be known; but the human factor has been very great. Such mighty beasts as the mammoth, the mastodon, the sabre-toothed tiger and the sloth, as well as the giant varieties of elk and bison, may well have reached their climax when man arrived with bludgeons, flint weapons and devices to quicken their ultimate doom. At all events, they gradually disappeared and their lesser relatives are most conspicuous in the menageries

and the exploits of the big-game hunters of the present generation.

In the seas the effects of altered temperature were likewise manifested. During the Mesozoic the warm waters of the present temperate zones permitted a wide community of marine life in all its forms. During the cold of the Pleistocene all the warm-water life was banished to the tropics. The gigantic sharks, which had long been the scourge of the seas, disappeared utterly, and their smaller descendants are now confined to tropical waters and the warm oceanic streams. The teleosts, better able to adapt themselves to the lowered temperature north and south, gradually assumed their present status and variety.

Quite as remarkable as the evolution of land mammals, has been the adaptation of many species to aquatic habits. It required about 10,000,000 years for the whale to evolve from a type similar to the existing tree shrew. And this instance is typical of the evolution of every other species of mammals, including man, as all have sprung from the same original stock.

Such are the outlines of the history of life to the present time. Whatever may be the fundamental factors of evolution and whether or not they may be discovered, the fact of this great process of nature is no longer open to rational doubt or debate.[20]

CHAPTER VI

A PREHISTORIC PEDIGREE

PRIMITIVE EUROPEANS

IT HAS always been the lament of paleontologists that the record is incomplete. Nature itself rebels at the general preservation of the untold myriads of once living things, which perish and decay that their successors may live. Only here and there and now and then could fossils have been formed or preserved. Insects have been caught in liquid amber and held intact for ages. Everyone has seen the perfect casts of creatures embedded in sediment that in course of time became stone. Some bones and wood that became fossils have lost their original character. The dead tissues were infiltrated with silica, lime or other mineral in solution; the organic structure disappeared and the invading material hardened into the form it replaced. Fossils of human remains are few, especially those formed during the earliest stages of the race. The characteristics that made the race possible would have prevented the dead from being left in situations favorable to the preservation of the bones except in rare instances; and the places where the oldest are most likely to be found have not as yet been searched.

Direct proof, therefore, of the origin of the human species is wanting. If, however, the same kind of indirect evidence and the deductions from it that indicate origin are deemed conclusive as to other species, the origin of man is explained. Embryology and physiology demonstrate, as will be shown, that the physical evolution of man has proceeded in the same manner as with all the higher types of mammals and that there are no physical reasons why it has not been in response to the same organic laws. Moreover, the evidence of evolution since the species originated is so clear and con-

clusive that all reasonable doubt has been removed. The proofs of organic change during any part of the career of a species is indirect evidence that the preceding processes were likewise an evolution. Such phenomena have appeared during the course of all orders. As there is no evidence to the contrary, evolution—whatever the causes—is regarded as the general law of organic development.

The reason for the reluctance of many minds to accept the theory of the evolution of man from a lower order is seen in the character of the controversy after the theory was first announced. Darwin's *Origin of Species* was published in 1859; the sequel, which had been clearly foreshadowed, *The Descent of Man,* appeared in 1871. For several years attention to the subject was mostly confined to scientists; but the circle of interest gradually broadened until evolution became a current topic in the press and on the platform. The theory was violently assailed. The acrimony of the attack was due to the radical challenge of ideas which had long prevailed for the most part in accord with theological doctrine.[21] The average mind, with such preposessions, was naturally shocked by the proposition that man evolved from a lower order of animals; that order, from one still lower; and so on down the scale. The theory, however, steadily won adherents by the weight of the evidence, which has greatly increased since Darwin's time, without any proof whatsoever to the contrary. To the leaders in science the evolutionary origin of man appears to be as certain as the evolution of birds from reptiles. The acceptance of this conclusion was of course aided by the prior geological proofs of the great age of the earth and the long duration and the progressive forms of life upon it. The first step was taken when the fact was established that man, as such, existed tens of thousands of years before the dawn of recorded history in a stage of development far below the most inferior savage tribes of the present day.

The most graphic and impressive evidences of the primitive phases of human evolution are fossil skulls and bones

found at different times and in divers places. Fortunately for their preservation and study most of them were discovered during the period when their true significance could be understood.

The earliest trace of man in Europe yet known was found in the sands of Mauer, near Heidelburg, Germany, in 1907. It consists only of a lower jaw, which, separated from the skull, had been carried with the sands of an ancient river-drift. The teeth are perfectly preserved and show conclusively that the jaw is human; but other characteristics place the specimen at a low position in the human scale. Here, as with all such finds, geology completes the story. The enveloping deposit and other fossil remains found there fix the period of the "Heidelburg Man." He lived in the Second Inter-Glacial, about 375,000 years ago.

Acute interest in the antiquity of man was revived in 1911 by the discovery of fragments of a skull shattered by workmen in an excavation at Piltdown, in Sussex, England. Subsequent search revealed the right half of a jaw, a canine tooth and a pair of nasal bones. All were in a good state of preservation; but it is somewhat uncertain whether the jawbone belongs to the skull found or to that of another species. Near the specimens were deposited various other evidences—fossil bones and flint eoliths—that betoken their period, probably later than that of the "Heidelburg Man." They indicate a different branch of the human family, at a time when England was part of the European continent. It is significant that the main difference of opinion as to this skull among experts relates to its age, some maintaining that it is much older than the Heidelburg specimen.

The next known of the human species, as to which much information has been gradually collected, is the Neanderthal race, so called from the discovery in 1856 of a skull and some other bones in the valley of that name on the Düssel River, Germany. As this was about the time the Darwinian Theory was put forth it started exhaustive study. At Gibraltar, twelve years before, a well preserved skull of

the same race had been found; but so little was known of the circumstances and surroundings that its significance was not recognized, particularly as the origin of man was not then in controversy. In recent years a large number of skulls, skeletons and relics of the same race have been exhumed.

The geological and other proofs of the age in which this race flourished, the physiological evidence of the stage of their development, the flint weapons and implements they made and used, together with the caves and other sites where they worked or dwelt, illustrate very completely the manner of life they led, the climatic conditions, the forests in which they roamed, the perils they encountered and the foods they ate. All these features have been minutely described by men who have devoted to the study a degree of discernment, ingenuity, and logic that compel the admiration even of those whom training and experience have qualified to analyze and weigh evidence in the most complicated transactions of modern life.

Evidently the Neanderthal race appeared about 50,000 years ago. Its superiority over human types that previously existed there, if we may judge by the "Heidelburg Man", enabled it to overrun at least western Europe during some two hundred and fifty centuries. It then in turn gave way to another and higher type, the Cro-Magnon, which through another long period evolved slowly improving methods and attained a higher plane of life.

From the fact that the Cro-Magnons (so-called after the name of a place where remains were found) at the time of their appearance in Europe displayed a degree and quality of industry and art not possessed by their predecessors, it is manifest that they brought it from elsewhere. They migrated from Asia through northern Africa. Their physical characteristics were clearly Asiatic and not African and the trail of their migration is known. Their distinctive traits, physical and mental, and their great and advanced differences from the Neanderthals indicate that Europe was not the seat of the origin of man or even of the early period of

his evolution. With the early Cro-Magnons were members of still another distinct race. Skeletons of the so-called Grimaldi (from the name of the grotto where they were found), belonging to that period, are of a negroid and dwarf type. They are so strikingly different, from any other European type of that period, as to show an enormous lapse of time for their divergence from the original human stock. The Grimaldi in Europe were probably brought there from Africa by the Cro-Magnons.

The ascendancy of this great race lasted for more than 15,000 years. It was succeeded by several other distinct types, which had found their way into Europe from various quarters in the footsteps of their predecessors.

If the stages of human development during these long epochs were disclosed only by skeletal remains, particularly skulls and jaws, the essential facts would be quite apparent; but they are also shown by another class of evidence quite as decisive.

FLINTS

Throughout the world human races and tribes in a primitive stage have used flint for weapons and other purposes. It was practically the only suitable material before metals were known. It was to be had in abundance, and it has survived unchanged from the forms in which it was used. The variety and different shapes and styles employed during successive periods show improvement in skill and corresponding advance in mental capacity and habits of life. More kinds were needed, and they were better fashioned and adapted to the increasing uses to which they were put.

The origin of flint is somewhat obscure; but it is always found with deposits of chalk, where it was formed chemically. As limestones were originally similar to chalk formations they frequently contain the same product, which, slightly altered in character, is termed chert. These facts account for the abundant supply of flint in most parts of the world. Much of France was submerged during the

Cretaceous, when most of the existing chalk deposits were laid. Thus flint in great plenty was ready to the hands of the early races that lived there.

It was first used in the accidental but convenient forms (eoliths) in which they were found before skill was developed to shape them into artifacts. Worked flints of the earliest type are termed Chellean, because they were first discovered at Chelles-sur-Marne. They are rude and but partly fashioned—eoliths with more or less work upon them to make them serviceable. They graduate downward to mere fragments without manual fashioning, such as were found with the Piltdown remains and elsewhere, and are thus known to be the form in which flints were first put to human use. There is no reason to suppose that the working of flints originated in one place and then spread by imitation. The use of eoliths would certainly not have so begun, and improvement of them would have followed as a matter of course. The chipping of flints, therefore, was a common process taken up everywhere instinctively as soon as man in a primitive state attained intelligence enough to see the need. For this reason specimens of each of the several grades of shape and workmanship wherever found are quite similar and true to type, allowing for minor differences of technique and style that would be the normal result of local practice.

The problem of the duration of the pre-Chellan period in Europe is of course identical with that of the rise of the human species in that quarter to the grade of the Neanderthals; and the estimates differ accordingly. Whatever the time, it must be measured by tens of thousands of years. The subsequent course of development to the age of metals is similarly gauged by the quality of the workmanship displayed and at length by nascent efforts to represent objects by drawing and carving. This long process of development during what is fitly styled the Old Stone Age has been so fully established in all its aspects that the successive stages may be described briefly without reference to the numerous

examples which have accumulated through many years of thorough investigation. These specimens have naturally increased in number in proportion to the improvement of conditions and mentality and the probable increase of the race during the later periods.

The successive stages of workmanship on flints are the Acheulean and Mousterian of the Neanderthals; the Aurignacian, Solutrean and Magdalenian of the Cro-Magnons; and the Azilian-Tardenoisian of the mixed peoples of the succeeding period to the beginning of the Neolihic Age. These names, as usual, are derived from places where important exhibits were found.

ACHEULEAN FLINT-WORK

In the Acheulean period the camps of the flint workers were usually on open ground, where the soil blown by the winds afterward covered and retained the evidence. The stations were near the supply of materials and therefore indicate that they were chosen for the preparation of flints rather than for habitation. Some stations were frequented for that purpose during the entire paleolithic age by successive races. At the grotto of Castillo, in northern Spain, deposits many feet in thickness accumulated. They formed so many characteristic strata that they present an epitome of the flint industry of western Europe from Acheulean time to the Age of Bronze. The stations are very numerous in Italy. In France, thirty are known, besides others in Portugal, Spain, England, Germany, Austria and Poland.

The workmanship throughout the period was very uniform. It was much more skillful than the Chellean, and the forms were more symmetrical. Toward the close of the period there was a marked improvement in technique, some of the smaller implements being very superior. Also the increased number of forms shows a greater diversity of uses and a corresponding advance in the qualities of the users.

There is no indication that the Neanderthals then lived

in caves or sheltered places. They were doubtless nomadic. This appears from the character and uniformity of their flints wherever found and may be implied from the genial climate that prevailed over the regions they inhabited during this period.

The climatic conditions supply important data in correlating the facts of human evolution in Europe with the results of recent researches elsewhere and should be borne clearly in mind.

The second glaciation was much the greatest of the four principal phases during the Ice Age. The race represented by the "Heidelburg Man" lived in the long interim between the second and the third glacial periods. The latter is supposed to have begun about 120,000 years ago, and the period of advance and retreat to have lasted about 20,000 years; but the extent was much less than that of the second. The Neanderthals appeared in the succeeding inter-glacial stage, which began, according to the most generally accepted estimates, about 100,000 years ago. The Chellean and Acheulean flint-workers lived in a climate more genial than that of today in western Europe.

Toward the close of the Acheulean the conditions began to change. The fourth glaciation had begun. Although it was less extensive than the third, the consequences to the flora and fauna of western Europe were profound. The glacial accumulations centered in Scandanavia and the Alps, from which there were two very similar advances, the recession between being only partial. At first the climate became cool and dry, except in the immediate vicinity of the ice. Afterward lower temperatures and great dampness prevailed, with some moderation between the two glacial advances. The final recession ended not less than 20,000 years ago. During the cold seasons the inhabitants were driven to shelter. The flint-workers who continued their employment sought the protection of cliffs and the entrances to caves. The first evidence of the use of fire is found in charred wood and bones among deposits at the sites of the flint industry.

THE MOUSTERIAN

The beginning of the new conditions brought on the Mousterian period. The late Acheulean was the climax of a gradual but steady improvement in the workmanship of the Neanderthals beginning at the close of the Chellean. During the Mousterian the quality of the work is usually inferior and its character distinctly different. The technique is good, but it shows less attention to form and detail. Industry in general showed no progress or invention. The principal change was the use of flakes of flint flat on one side to save work on the other. Some old types of implements were abandoned and new ones were made for other purposes, due to changes in the conditions of life. The cold climate compelled the use of skins for clothing, and to prepare to fasten them together required other tools.

The places of abode of such as remained in the old habitus, apparently caves for the most part, supplied but little comfort. Even through the dryest seasons the collected moisture trickled down the walls. The condition of the vertebræ of both animals and human beings of that period often shows signs of swelling and inflammation caused by long exposure to the damp. Crowding in caves and shelters tended to reduce the vigor of a people which had always lived in the open. As might be expected from such conditions, the beginnings of superstition are seen, for there are traces of primitive religious ideas and ceremonial. Yet this folk were brave and hardy. Weaklings must soon have perished. Only the fearless and sturdy could have captured or killed the mighty animals upon whose flesh they subsisted. It is significant that there are nearly as many known Mousterian stations as there are Acheulean.

The rigor of the climate at the maxima of the fourth glaciation and the changed conditions of human life may be inferred from the revolution of species, both plant and animal, of the regions affected. In place of the subtropical fauna known to the Neanderthals of the previous period now roamed the mammoth, the wooly rhinoceros, the rein-

deer, the musk-ox, the arctic fox and many other species characteristic of a cold habitat, many being now extinct. Corresponding vegetation replaced the copius and fruitful growths which could no longer exist there. These transformations must have radically affected the former type of human beings that dwelt there and checked their further development. This conclusion is enforced by like phenomena too often seen in biological history to admit of doubt. That the Neanderthals should have yielded to a superior race when it came from the south after the untoward conditions had begun was inevitable. The arrival of Cro-Magnons marked the beginning of a new epoch.

THE CRO-MAGNON RACE

The Cro-Magnons were physically as fine a race of human beings as ever existed. They were of great stature, straight and well proportioned, with large and nobly modelled skulls. With them the brain had reached the climax of capacity. Within the limit of that capacity lay the future of the human species. It is not to be supposed that a race appearing at that time could have reached such physical perfection without corresponding antecedents dating far beyond the Acheulean period. If that be true, the Heidelburg, Piltdown and Neanderthal races are merely proofs of stages through which the ancestry of the Cro-Magnons had passed long before.

It is quite certain that this type appeared in Europe between 25,000 and 30,000 years ago. The disappearance of the Neanderthals was abrupt and complete. They were probably exterminated. They were no match for an enemy large in number, more powerful in body and mind and armed with better weapons. There is no evidence that the Neanderthals had the bow and arrow, which the Cro-Magnons doubtless possessed then as they did later. The inferior race was probably disdained by the conquerors, as there is no indication of an intermingling of blood.

The Cro-Magnons were chiefly of nomadic habit, to which

they were perfectly suited and in a favorable environment, yet their employments were far more diversified than those of their predecessors, as appears from the great variety of weapons, tools, implements and ornaments made and used by them. The Neanderthals were without an esthetic sense, a distinct trait of the Cro-Magnons and later developed to a marked degree. The burial customs of both races were so similar that they may be regarded as normal primitive tokens of regard for the departed: weapons, implements, ornaments and food were interred with the dead.

As the advent of the Cro-Magnons in Europe was during the final phases of the glacial period the climate had already improved, and it gradually became much the same as that which now prevails there. Plant and animal life responded to the change. Yet the change was not the restoration of former conditions. The close of the Ice Age, as already shown in another connection, marked a transition from the old world to the new. Many previous forms of life gradually but entirely vanished, while the descendants of others underwent more or less modification. Many species migrated thither from regions which had not been directly affected by the ice. Natural forces in a changed environment likewise reacted upon the human species that dwelt there. All this is clearly shown by specific evidence.

A considerable time elapsed before the moderation of the climate allowed the Cro-Magnons to pursue a more free and improvident course of life in the open. The summers slowly became warmer, dryer and more stimulating, though the winters were still severe. Caverns and other natural shelters were needful during the inclement seasons. The habitations and flint-stations used in former times were taken over. Not until much later did the salubrity of the climate permit the use of open stations and the more scattered dwelling places and variant modes of life apparent from the many vestiges of that age. As the huge animals of the Mousterian dwindled away and finally vanished the more modern fauna, including great herds of wild cattle and horses, made their

appearance. The effects of these changes upon human development in that region might be inferred; but they are attested in the most graphic manner by the tangible proofs of cultural development.

THE AURIGNACIAN ARTS

The stages of Cro-Magnon culture are distinct and characteristic. The first (Aurignacian) is much superior to Acheulean achievement, though still primitive. Perhaps the fact of most significance is shown by rude sketches of huts or shelters made of logs and covered with hides. These dwellings were evidently located at points most convenient for hunting and fishing, in a country where game of many kinds abounded. The building of these shelters was doubtless the first architectural practice in western Europe.

The art impulse was strong and evidently general. That it was natural to them is seen in the early and rapid process of its development, especially in attempts to picture the animals most familiar to them. These sketches begin with crude efforts to represent the huge creatures yet in the country when the Cro-Magnons arrived, then of others that succeeded. The quality of art thus initiated is strikingly progressive. Attempts in color were often made, the pigments being mixtures of ochre, manganese and other common ingredients. Besides these essays at mural painting, modeling in the round was undertaken. Quite naturally it is the female form that is represented; and if the corpulence common to most of the figures shows a sedentary life the women were favored in the activities of the time. Carving on stone, bone and ivory was practiced, with some taste and dexterity. Staffs and wands, made from deer antlers, apparently for ceremonial use, and also bas-reliefs and incipient sculpture are among the exhibits of Aurignacian art. From construction to decoration is a natural and easy step.

It is to be inferred from all these interests and employments that the making of the necessary tools and implements was in itself a very considerable industry. The in-

crease in the number of stations and the wider territory in which they are found show not merely the greater volume of the industry, but a probable growth of population. Not only is the workmanship finer than that of the Acheulean, but manifestly of different origin, as might be expected of a more highly developed people from a source where industry had long been in an advanced stage. The artistic traits displayed by the earliest Cro-Magnons could have been evolved only by a protracted period of practice among their antecedents. The many kinds of small articles of personal adornment found with and upon buried remains point to customs so general as to require a vast time for them to become an ordinary detail in the life of a people even at that stage. Nor were these traces of the Aurignacian confined to western Europe. They girt the Mediterranean, and evince a variety of style and origin that could have come only from invention in many places and wide imitation.

THE SOLUTREAN

The chief method of workmanship on flint during the Solutrean epoch, which followed, is so different from that employed during the Aurignacian and appears so abruptly as to show an independent origin. The so-called "Solutrean retouch" was executed by pressure which removed thin, fine flakes, thus producing sharp edges and perfect symmetry. The barb now appears for the first time. The products of this technique mark the climax of the Solutrean flint industry; and they are due to the speedy adoption of a new method because of its manifest superiority. Of course such a method might have been discovered by expert workers; but other facts point to a foreign influence. These facts bear strongly on the problem of the source from which all the human species radiated.

The Aurignacian technique was far more widely spread than the Solutrean, which is found nowhere else around the Mediterranean. It doubtless entered Europe from Asia directly and not through northern Africa. This conclusion

is supported by the appearance at this time along the Danube of a race distinctly different from any which had previously inhabitated Europe, so far as yet known. This race (The Brünn) was by no means equal to the Cro-Magnons in general capacity, but it had somehow acquired the best method of working flints. This advantage appears to have been appreciated by their neighbors, who soon brought it into common use, for no remains of the Brünn race have been found in France.

The progress of art in the Solutrean was not equal to that of the flint industry, yet on the whole the quality was sustained. Specimens of both linear and plastic forms are numerous, and a beginning was made in animal sculpture. Quite elaborately engraved implements of reindeer horn are characteristic of the period. It may be assumed that more attention was paid to clothing, as well-made needles of bone neatly pierced at one end have been found, and the like were doubtless in common use. Indeed, bone had already been substituted for flint in many tools and ornaments.

THE MAGDALENIAN

The Magdalenian closed the long career of the Cro-Magnon race. The beginning of that epoch is assigned at not later than 16,000 B.C., the combined duration of the Aurignacian and Solutrean having been about 9,000 years, according to the estimates most generally accepted. The epoch lasted about 6,000 years. During that time climatic changes materially affected the conditions of life. After the period opened there was another glacial advance from the same centers as before. It was less extensive than any previous one, yet severe enough in its effects to leave unmistakable traces in the remains of plant and animal life then existing within the range of its influence. The ice then retreated and former conditions were renewed. Later, toward the close of the Magdalenian, the process was repeated with like results. It was during the interval of the two glacial advances that the culture of the epoch reached its highest development.

Flint was still used for many ordinary purposes, but those purposes were as well served by rougher workmanship. Wherever practicable bone, horn and ivory were substituted, and they were better materials for artistic treatment, which accordingly progressed. This phase of Magdalenian art and industry is very prominent. The use of bone implements led to several kinds of barbed javelins for the hunt and harpoons for spearing fish. As these harpoons now first appeared it may be that interest in the chase was divided with fishing to a greater degree than ever before. The mere variety of weapons, implements and utensils suggests the many different activities that must have arisen; for most of them required such special skill that they could not have been general. The fact implies ranks and occupations more or less distinct and recognized. It is not surprising, therefore, that among such people the natural promptings of their alert intelligence should have struggled for artistic expression in every primitive form and applauded its exercise. Crude and fragmentary as these efforts were in drawing, graving, modeling, sculpture and even painting, they display with unanswerable force the process of mental evolution through which the highest intellectual faculties began their ascent.

From the variety of shells and other objects used for ornament and drawn from many different and remote places it is possible that there was some system of barter and communication. The tribesmen must have wandered far and wide and returned with the results of their primitive trade. There are no indications of battle or conquest. At the height of their dominance the Cro-Magnons were spread throughout central and western Europe. They had no rivals and absorbed no streams of incoming alien blood. Their rule was distinctive and their culture was their own. Whatever their achievement owed to external and intrusive ideas and customs, the foreign factors were subordinated to the native or moulded into harmony with them. The Magdalenian culture was not Mediterranean; no stations are known in those regions that show either the origin or the

influence of its distinctive features. When the epoch drew to a close that mighty race was approaching extinction, except as its blood was mixed and diluted with that of its successors. The cause of its disappearance is unknown, though there is some evidence of physical and mental decline. It had probably passed through a cycle of existence, like so many other races before and since.

THE CLOSE OF THE OLD STONE AGE

The disappearance of the Cro-Magnons was quite as abrupt as that of the Neanderthals and almost as complete. A small and decreasing number lingered in southern France and northern Spain; but even these eventually died out, leaving no descendants. All their distinctive traits vanished with them. Their successors, of several different races and types from different quarters, were at least alike in their lack of artistic tendencies. For them sheer existence appears to have been the sole object of their efforts. Yet they were not such mighty hunters as the Cro-Magnons, who enjoyed the excitement of the chase. Fish and venison were apparently their staple foods. They were rough-and-ready barbarians; and their weapons, tools and utensils were designed for use and not for ornament. There are some indications that war was a condition of the time. Hardy and savage tribes with different speech and traditions must have come into collision. An environment of hostility and danger would thus account for the rude and inartistic quality of the industrial remnants of the Azilian-Tardenoisian epoch, which closed the old Stone Age in Europe.

The epoch ended about 7,000 B. C. The climate had been cool and moist, and the inhabitants generally lived in grottos, caves and sheltered places. Vast forests covered much of the continent. The rivers and streams abounded with fish, a great variety of edible game roamed the goods, and herds of deer, wild cattle and horses ranged the plains. If there were races of men from other regions where the increase of numbers had decreased their resources and op-

portunities they would have migrated to other scenes where life held greater promise. That course was followed so often in after times as to cause some of the most tragic events in history. The evidence is conclusive that such migrations occurred in paleolithic times. Toward the end of that age such causes operated to an increased degree. Hordes from the congested East debouched into the rich and alluring wilderness abroad. Western Europe thus became the terminal region of these migrations until Columbus opened the way to the New World.

Although rude and inartistic, the invading races were by no means backward in mental capacity. They lacked taste for ornaments, but they had pots and kettles and had somewhere gained some knowledge of metal. They were ancestors of races that inhabit Europe and America to-day. It stands to reason, therefore, that the development of the brain and knowledge possessed by their antecedents took place elsewhere than in Europe and extended to a period far more remote than that to which the earliest European races belong.[22]

PRIMITIVE MAN IN THE NILE VALLEY

The Stone Age of Europe, together with the natural history of the anthropoids, has hitherto been the basis of all speculations as to the origin of man. The ablest investigators of those races, however, have more and more tended to the conclusion that the history of the first Europeans is that of an evolutionary phase too late to disclose origin except as illustrating the general law that applies to origin as well as to subsequent evolution. Recent researches in another region have thrown a new light upon the whole subject.

The human races that inhabited Europe during the Paleolithic Age contended with disadvantages not suffered by other human races in regions not materially affected by the severe conditions of the Pleistocene. The progress of the Neanderthals and the Cro-Magnons was repeatedly stayed

by advances of the ice. The total time of these obstructions covered many thousands of years. In a different environment where the momentum of progress was not arrested by such conditions we should expect to find proofs of a much earlier evolution of mind than could have been possible in Europe; and we should expect to find them in the regions where the earliest civilizations appeared. Egypt and Mesopotamia being such regions, the origin of their cultures was probably not far from those natural centers. Whatever may be the results of future investigation, enough has already been learned as to the course of evolution in Egypt to disturb any idea that the Heidelburg and Neanderthal races were the earliest in fact instead of being much later representatives of types which had existed elsewhere very long before, and also to discredit any alleged evidence that a distinctly pre-human species has been brought to light.

During the entire Ice Age in Europe what is now Sahara Desert was a fertile country with abundant rainfall. It became a desert in later times. There has been no change of mean temperature there in several thousand years. The cause of the change to desert conditions is thought by some to be the rise of dunes along the Soudan, which gradually lessened and finally prevented the rainfall. Be this as it may, paleolithic man thrived there during the period of the Heidelburg race, with a flint industry as far developed as the Chellean. But it was the region of the Nile that supplied the most ideal conditions for human evolution. This was in part the result of a peculiar geologic event.

During the time when the lower levels of the later Pliocene were formed the coast line of the Mediterranean was as far south as the present site of Cairo. Two fractures, varying from 4 to 15 miles apart, then occurred through opposite sides of that place and extended southerly for some 400 miles. They produced what is known as a "block fault." This block between the two fractures in the Eocene limestone sank about 800 feet, forming a trough afterward

prolonged by other displacements to the site of Gebelen, about 450 miles from Cairo. Into this trough the sea entered for a distance of 90 miles. Here was the first mouth of the Nile later on, perhaps in the period of the European First Inter-Glacial. Streams produced by the extraordinary pluvial conditions of the time poured into the depression. Sediments and detritus on the bottom were swept along by the current until they dammed the discharge of the water into the bay. A lake or a series of lakes was thus formed, lasting for several thousand years until the Nile originated and broke through. This situation made possible the most remarkable development of its kind in the world.

In the course of time the bottom of the lake was covered with conglomerate masses of gravels, marls and limestones, and terraces of limestone and indurated gravel were built up along the sides. The fossils contained in these deposits show that the period of their formation corresponds with the late Pliocene and early Pleistocene. After the Nile forced the barrier and drained the lake much smaller terraces were formed of mud, sand and fine gravel, rising in gentle slopes along the edges of the land that has been the ribbon of cultivated soil in Egypt from prehistoric times. The depth of the river deposits, which form the present alluvial floor of the Nile Valley, ranges from 30 feet at Thebes to 130 feet in the Delta. So deep an accumulation could not have been possible in the relatively short time since the close of the Pleistocene. According to the present estimates, therefore, the lower half of the mixed clays and sands that comprise so much of the Nile alluvium was laid concurrently with the period of the Fourth Glacial. Nowhere in any of these deposits, lake or river, have been found any evidences whatever of a fauna characteristic of the glacial conditions of Europe. On the contrary, buffalo horns, and teeth of the elephant and the hippo have been exhumed. Even the lake marls of the Fayum have yielded teeth, hoofs and leg-bones of the horse, and also the mandible of a man! There can be no reasonable

doubt that the period of the lower river alluvium corresponds to the Fourth Glacial. That fact established, the provisional hypothesis advanced by Breasted as to the time division of the preceding formations seems warranted: the lacustrine deposits took place during the late Pliocene and the First Glacial; the upper river terrace, during the Second Glacial; and the lower, during the Third Glacial. Whether or not this correlation be finally established, other proofs show conclusively that human development in the Nile Valley was far in advance of that in Europe at all the early stages.

During this immense lapse of time the Sahara plateau was habitable, and from the discoveries already made it seems probable that men able to produce flint implements dwelt along the foot of the cliffs above the lake near the present site of Thebes during the period of the First Glacial in Europe. Many rude artifacts made by these men appear to have been swept from the shores into the lake, where they were found in the lacustrine terraces 50 feet or more below the alternate strata of those formations.

Along the crest of the cliffs just above Thebes are stations where flints were fashioned at a very remote period. When the lake was drained and the Nile current began to flow through the bed the heavy erosion of the pluvial period carried great masses of rock debris into the valley. Of this the upper river terrace was in part formed. Many of the flints that lay on the ground were carried away by the movement and are now found embedded in the terrace. The conglomerate materials of the formation manifestly came from the neighboring heights, and the flints found within it are of the same type and workmanship as those still found there. The conclusion is obvious.

The river was then from 45 to 60 feet above its present highest level. As its volume decreased (probably during the period of the Second Inter-Glacial) the people began to shift into the valley, transferring their work stations to the terrace, where some of their implements have been

found. In front of the cliffs are scattered the hearths of this primitive folk; and here, it is not unlikely, wattle huts were built somewhat later. On the convenient rocks of the cliffs the aboriginal artist amused his hours of idleness by scratching the forms of animals he had hunted, for these drawings belong to this stage of Egyptian life, at a time when the Neanderthals were only beginning their career in Europe. They had learned to build floats of reeds for crossing the river, and these were soon displaced by wooden boats, which are also pictured on the cliffs.

As the waters of the Nile receded the dwellers on the banks followed until the river had sunk to its present level. It was not until the Fourth Glacial in Europe that the river began the annual overflow and deposit of alluvial soil. When this phenomenon appeared the dwellers upon the spaces overflowed withdrew to higher ground. The process of this inundation is known to have been gradual until it reached the maximum spread which has been annually repeated with great constancy during historic times. As the alluvium slowly widened it buried the vestiges of life that were not removed. Thus in the neighborhood of Thebes such relics are covered to a depth of 30 feet. Buried there, it may be assumed, lie many of the proofs of the successive phases of progress to a degree of civilization known to exist at the beginning of the pre-dynastic history of Egypt.

If nothing were known of the vast interval between the early settlements along the Nile at the beginning of the Fourth Glacial and the close of the Paleolithic Age of Europe, the course of human evolution in the Nile Valley could be very accurately discerned. The emergence at that time of conditions denoting a relatively high degree of civilization would attest an unbroken and steadily accelerated development of industry, agriculture, trade, art, society and government. These conditions could not be explained otherwise. But there are proofs, direct and indirect, of facts that have no other meaning.

EARLY PROGRESS OF THE NILE PEOPLE

The entire region was free from the rigorous and changeable climates that prevailed in Europe. There were no conditions that checked or abated the course of development. During the thousands of years when the human species in Europe were struggling with adverse conditions and leading a precarious life in conflict with fierce and formidable beasts, the Egyptians enjoyed a salubrious climate and freedom from the hardships and dangers of the European wilderness. There were no causes in nature to retard their progress; and that it was not retarded is shown by early tombs and the Pyramids, erected by a highly organized community far advanced in development when the barbarians of Europe were still in their Neolithic Age.

From borings made north of Cairo it has been determined that the average rate of alluvial deposit during the last 4,000 years has been about 4 inches per century. It was probably less at first and increased very gradually. These borings found pottery at a depth of nearly 60 feet. This shows that the time when the pottery was left there was from 15,000 to 18,000 years ago, more probably the latter. If the inhabitants at that age generally used such pottery—everywhere one of the first proofs of development beyond sheer savagery—their progress in other respects must have corresponded, for these vessels are of various kinds, ornamental as well as useful.

Already the causes that made the Sahara a desert had begun to act, and the rainfall in Egypt was gradually diminishing. This would have compelled the dwellers in the valley to depend more and more upon the annual overflow of the Nile as the main source of their welfare. At that period, therefore, the rank growths along the alluvial banks were removed and the beginnings of a regular agriculture were made. The grasses from which the cereals have come were cultivated, animals were domesticated and other forms of industry and consequent trade began. These phases of development are as yet deductions, but from fundamental

facts that make them presumptively valid. Moreover, they are confirmed by another class of evidence not less cogent.

Since the arable land was limited it would have been used less and less for the burial of the dead. During the period when the alluvium advanced, burial places previously nearby would have been covered. At length the dead would have been interred on the terraces out of the way of living. Excavations have not yet been made in search for these supposed burial places; but the earliest cemeteries known are upon the higher ground opposite the alluvium. These cemeteries have been quite thoroughly investigated, and though they do not extend actual knowledge to the purely Neolithic Age of Egypt, the period when the probable burials occurred and the cultural conditions assumed to have then existed are in accord with the theory of prior gradual progression.

These interments were made not later than 4000 B. C. The flint workmanship found there is unsurpassed anywhere in the world at any time. The "ripple-flaked" knives, for example, are so perfect in symmetry and so exquisitely fashioned that they must have been made by craftsmen who delighted in their skill. Yet the flints are merely incidental. As shown by other articles interred with the dead, the making of pottery, which had started long before, had been developed to a fine art. The many kinds for various uses point to a great industry carried on by expert artisans. Much of the pottery was made from the clay sediment of the Nile shaped and baked in regular forms. Circular pots and vases show the use of the potter's wheel; and their decoration, the combined result of craftsmanship and taste. Some forms have black tops, while others are of polished red with white, brown or black lines incised. Vessels of stone, bored and finely worked by hand, likewise betoken the advanced state of the stone-cutter's craft. There also abound specimens that display the varied means employed for personal adornment, such as bracelets, rings, combs and hairpins of ivory and palettes of slate for mixing face-paint.

More significant are the evidences of textile skill. The dead were laid on mats of woven reeds bound with flaxen cord. Some of the bodies were wrapped in a sort of linen cloth, by far the earliest known. That linen represents a culture of flax which must have begun along the Nile very long before.

Nor was that culture exceptional. From the remains of those early dead and in jars buried with them the grains—barley, millet and wheat—then used for food have also been found. The originals from which these grains were produced still grow wild in western Asia. All the varieties of wheat have sprung from emmer, which these dwellers in the Nile valley had already improved to a high degree. The domestication of animals and water fowls at that period has not been demonstrated by actual proofs; but it may fairly be inferred from the state of agriculture. All the details of the practice are shown at a somewhat later period on the pre-dynastic reliefs.[23]

THE PROBABLE SEAT OF HUMAN ORIGIN

Whether or not northern Africa was the scene of the origin of man, the evidence now at hand (though the real investigation has only begun) clearly indicates that it was the seat of the earliest development of the human mind. In any event, it is apparent that the natural history of early man in Europe presents a local phase and not the original development. If the chronology of that history to the Mousterian, in the middle of the Third Inter-Glacial, were disregarded, and the duration shortened at least one-half to allow for the retarding effects of the first, second and third glacial periods, it might serve as a provisional introduction to the known career of man in the Nile region to the beginning of the period of the Second Glacial, which was long before the Heidelburg race appeared in Europe. This would place the origin of the human species in the Tertiary, an opinion contrary to that which has hitherto obtained.

This conclusion is supported by other considerations. If the original human species arose in Africa, in the quarter where the earliest evidences are found, and later spread to western Asia, and the Neanderthals, like the Cro-Magnons, originally migrated thence, there must have been an enormous lapse of time before diverse types could have arisen from the first stock and increased to such numbers as to seek new regions and slowly penetrate thousands of miles of perilous wilderness to reach their final abode. Even if the Neanderthals came from northwestern Africa across the land bridges then existing, the conclusion here advanced is not materially disturbed. After knowledge of metals had reached the Ægean area, a thousand years passed before it came to Britain and Scandinavia. It was a thousand years after the beginning of Roman civilization that the reaction upon the barbarians of the north was strong enough to incite a successful invasion. The factor of time thus becomes a paramount factor of the problem. Furthermore, if this view of the remote origin of man be well founded it modifies or displaces another theory which has long been foremost in such speculations.

PITHECANTHROPUS

In 1891, near Trinil, Java, was found part of the skull of what has since been known as *Pithecanthropus erectus* (upright-standing ape-man). With it were unearthed two molar teeth and a left thigh bone. These remains, if all belong to the same individual, are parts of the only creature thus far discovered which had some characteristics of a pre-human species. Bones of other animals, including monkeys, found with the remains prove that all were deposited in the late Pliocene or early Pleistocene, when Java was joined with the Asiatic continent. The discovery of the so-called "missing link" aroused wide interest. The press of that day devoted no little space to the subject, and the discussion of it has continued to the present time.

Taken in connection with the low human development of

the Heidelburg, Piltdown and Neanderthal species alone, *Pithecanthropus* seemed to have great significance. If it were a member of a pre-human species, the fact of evolution agrees with the theory; hence evolutionists were tempted to draw that conclusion in the absence of evidence of a greater age of the human species than was then known. During recent years, however, on more mature consideration of the Trinil skull itself, eminent authorities have inclined to displace the species from the ancestral human line and regard it as belonging to a branch of the original generalized stock from which the human and anthropoid types have both come. This opinion is confirmed if the fact be established that man already existed as such during the epoch of the super-apes of Java. In that case, evidence of the direct line of human descent is yet to be discovered.

A solitary example of the Trinil species, without intermediate types with progressively human characteristics, does not in any view establish a position in the line of human ancestry, however lowly the appearance and habit of species in that line. It only shows that at a remote period a race of apes existed with more distinctly human resemblances than have been possessed before or since by any other anthropoids known. All this is quite obvious, but the implications are important to the theory of human evolution.

The so-called human characteristics seen in the simian types are chiefly the traits of incipient intelligence, possessed also in other degrees and other ways by many animals. Their peculiar evolution would not have been possible without them. Man, as a higher animal, has all these lower mental traits in combination as the basis of his higher faculties. The same kind and degree of intelligence is naturally displayed in the same manner by the creatures that possess it. In its earliest phases, therefore, the quality of intelligence lowest in the human scale would also be shown by the apes, though modified by other characteristics, mainly physical, which predominate. The capacity of the Trinil

skull is less than three-fourths of the brain capacity of the smallest specimen of the Neanderthal race yet found, though much greater than that of the chimpanzee. Despite its human resemblance in some particulars, the Trinil species was too remote from the human stock and too highly specialized to be ancestral in the evolution of the human brain.

THE ANTHROPOIDS

If the process of divergence of the Trinil type was similar to that so often seen in organic history as to illustrate the principle, the original human (as distinguished from the immediate pre-human) stock was as distinct from the original anthropoid as the anthropoid stocks are different from one another. As the causes which produced the anthropoids throughout their evolution operated decisively at the time of the divergence, the longer the time afterward the greater were the differences and the more fixed the special types. The powers which have enabled the human species to advance instead of being irretrievably moulded and fixed in type by circumstance have been due to the possession of a mental organ capable of surmounting natural obstacles that otherwise could not have been overcome. The disappearance of whole races of human beings is explained by their lack of brain, usually through physical deterioration, capable of standing the strain of conditions, while others were so constituted that they could and did or were not subjected to similar disadvantages. Apes, therefore, did not become human. A divergent branch from the primal source, the potential human line, became apes.

This aspect of the question should be clearly understood in order to avoid a common misapprehension of the theory of organic evolution. Much of the opposition to the Darwinian theory has been due to that misapprehension; and much of the discussion of the Trinil specimen has furthered it. Even many people who would otherwise accept the theory of biological origin and evolution refuse to recognize the ape as an ancestor. The reason may be sentiment or

prejudice, but it is none the less effective. To these it may be helpful to know that *Pithecanthropus* is nowise needful to the evolutionary origin of man.

The question whether the anthropoids appeared before or after the distinctively human stock is purely speculative, as proofs bearing upon it are yet wanting. The type apparently originated in one or more abortive variations in the process of mental evolution before the ultimate line was definitely established. Since that line was strong enough in the beginning to control its evolution afterward, it is reasonable to suppose that throughout the early stages the nascent human type was distinct from species in which mental limitations were impassably fixed. Whatever may have been the resemblance during the first stages of both types, the superior power of the pre-human line would have reacted sooner on the physical development; hence at the time the higher anthropoids attained their climax, man, though still in a lowly human stage was nevertheless distinctly human and was gradually adding to the volume of a brain already of necessity much greater than any anthropoid could have had. That brain, moreover, had the power of yet greater growth, which the brain of the ape did not have. Thus considered, the history of the anthropoids becomes more significant.

The record of the apes is very incomplete, but there is enough to mark the long term of their later evolution. The beginning has not been found. The remains of one of the forerunners of the great apes was exhumed in the desert near the Fayum, in Egypt. As that specimen was deposited in the Oligocene, the origin of the order must date earlier than the opening of the Tertiary. It resembled the gibbons, of which true arboreal types were in Europe early in the Miocene, and they continued there in various forms during the Pliocene. Other apes were also in Europe in both the Miocene and the Pliocene. In the Pliocene a generalized form related to the gibbon, the chimpanzee, the orang, and the gorilla lived among the Siwalik hills of Asia. It is

agreed that none of these types can be regarded as ancestral to man. Yet the common descent from the remote original source of the pre-human line is undoubted. The anatomy of paleolithic man compels this conclusion.

Much has been written concerning the process of man's structural evolution. That process is resolved by all authorities into four principal factors: the erect attitude, the opposable thumb, the power of speech and the growth of the brain. The latter must have been the cause of the others, though benefiting in turn by the effects. The earliest known apes walked more or less erect and were therefore dexterous in the use of their hands. Neither then nor later did they have the opposable thumb or the power of speech. The two upper grinders of the Trinil specimen more nearly resemble the form of the corresponding human teeth than do those of the gibbon, yet very clearly they do not confirm even in this detail the theory of the pre-human character of the animal. The thigh bone is so much like that of man that the creature walked erect and had full use of its arms and hands. The sensory areas of the brain—of touch, taste and vision—predominated. The central areas—of memory—were well developed, as with all the higher apes. The entire pre-frontal region was scanty, showing very slight ability to profit by experience. With such a rudimental mind, speech would not have been possible, nor would the probable form of the lower jaw have permitted. In seeking elsewhere for pre-human species the most promising geologic period is not in the Pleistocene of *Pithecanthropus* or even the late Pliocene. More probably, if the proofs ever come to light, they will be found in the lower Tertiary.

THE PRE-HUMAN SPECIES

Throughout biological history the phases of radical transition are the most difficult to trace and therefore the least certainly known. They were necessarily the most rapid. The chief causes were changes in environment, which bore most heavily and swiftly upon many forms of life subjected

to them. Highly specialized types, which could not conform disappeared, while those more generalized and therefore with more plastic organisms readily changed along with the conditions. The comparative speed of the evolution greatly reduced the number of individuals affected and so diminished the chances of their fossils being preserved and found.

The pre-human species were the most adaptable and responsive when conditions required, and their potential brain accelerated the process. Every succeeding change was hastened accordingly when the circumstances raised no hindrance. The human race no doubt began in the most favorable region and was aided by a congenial environment. Measured by years, the advance was relatively rapid when all the conditions were propitious, as it ever since has been. When we consider the slowness with which superstitions die and sound ideas penetrate the mind of the multitude, even amid the enlightenment of the present age, there is no cause to marvel at the vast periods of time required by primitive human progress to reach the dawn of civilization.

CHAPTER VII

MIND AND THE AGGREGATE

TRUE PSYCHOLOGY

INTELLECTUAL progress is the gradual adjustment of mind to matter. It has therefore been precisely in the ratio of the advance in knowledge of nature. And this is so because of the physical character of the brain. The primary function of the brain is to register sensations brought to it by the nervous system; and all sensations, at least in their origin, are produced by material means. All living tissues are more or less sensitive and thus respond to their environment. The processes of growth would otherwise be impossible.

Despite the enormous and ever-multiplying literature of psychology, the known facts that underly the science are greatly disproportionate to the superstructure of theory; and the most important principles are still in dispute. Even this situation shows a vast improvement over the former license of metaphysical speculation, which reveled in complete detachment from physical facts. The first great stage of a true mental science was achieved when psychology was brought within the definite boundaries of physiology.

The brain being a physical development, the laws of its evolution are the same as those which govern all animal growth and adaptation. Physiological functions necessitate communication of the parts and more or less central control of the combination. Each is dependent upon the others, and all are but different media of the forces, whatever they may be, that produce the varied phenomena of life. The human mind is the culmination of organic development, which had to pass through the successive stages of physical organization and aptitude to the point where consciousness

became objective and the powers of perception began to recognize the relation of cause and effect. And this has been through increase of function and the corresponding product of the means of exerting it. The origin and evolution of life are therefore coincident with the origin and evolution of mind; and the prime factors are wholly unknown. We are here brought through another avenue of approach to the problem of the constitution of matter and the cause of atomic and sub-atomic motion manifested in heat, light and electricity and the phenomena of chemical action.

ORIGIN AND EVOLUTION

The evolution of all forms of plant and animal life from one probable source and form very naturally suggests the idea that the origin itself was mechanistic. And that idea has of course been present from the beginning of philosophic thought; but it possessed no tangible foundation until the modern demonstration of the origin of species and the development of organic chemistry. Given the suitable conditions of temperature, moisture and essential elements of matter, biochemical combination, very minute and in the simplest form, became inevitable. Such is the prevailing opinion of men of science at the present day, notwithstanding the absence of any positive evidence of spontaneous generation. However, a multitude of facts have been slowly accumulating for the structure of proof; and the most important of these are the recent discoveries concerning the constitution of matter as the embodiment and vehicle of energy. Life is essentially a manifestation of energy, making use, so far as known, of the several forms with which science is familiar and acting through and upon familiar materials, though there are good grounds for suspecting the operation of another kind of energy, which has thus far eluded analysis, but which may be the dominating force in living things.

The mystery of life has been the most prolific source of speculation and has naturally led to the most pernicious dogmas that have afflicted mankind, through their controlling

influence upon thought and action. These dogmas range from the crude anarchy of chance to the centralized despotism of divine predestination, none of which find countenance in the principles affirmed by science. While this is not the place for discussion of the great subject that for generations has exercised a legion of writers on theology and metaphysics, a few observations from a practical point of view will be pertinent and may aid in correcting the erroneous assumption in some quarters that science is sheer materialism, in its restricted sense, and the negation of a Creative Purpose in the phenomena of nature.

If the adjustment of the waters and the atmosphere to the conditions which have made the earth an abode of life were to be regarded as the result of chance, the odds, within the definite law of probabilities, would be immeasurably against it. The factors of the problem are so many and so perfectly proportioned that only a mind reckless of all considerations of rational possibility can conceive that mere chance wrought these wonders out of chaos. But there can be no chaos in the primary meaning of the word. Even in the most heterogeneous mass, the elements composing it exist intact with all their properties, ever ready to separate or recombine in other forms according to the forces exerted upon them. So, when the chemical elements that enter into organic combination are multiplied into the other factors and this result into the marvelous attributes of the elements themselves, the existence of life and mind through blind chance is so remote that no one acquainted with the terms of the proposition would hazard a guess at such a solution. Yet, leaving out of thought the alternative Cause as beyond the reach of finite faculties, there is such ample scope for the operation of natural forces upon the diversity and instability of matter that the results are variable and contingent. This plasticity of circumstance is the medium of chance. And it is the inter-relation of all phases of the conditions that renders true science and philosophy synthetic.

For twenty-three centuries, from Empedocles to Darwin, the idea of evolution was germinating. Within fifty years from the publication of the *Origin of Species* the principle had won the unanimous acceptance of the scientific world. Those five decades mark the greatest and most salutary revolution in the history of thought; and this consequence would not have been possible but for the rapid progress of scientific methods, which brought about a new attitude of mind toward nature—the disposition to ascertain facts and to accept their logical import regardless of doctrines and preconceptions.[24]

That there is still some misapprehension of the true character and meaning of organic evolution is due to confounding the principle with criticism of Darwin's effort to explain it by what he termed natural and sexual selection, or, as put by Spencer, the survival of the fittest. This rationale was soon challenged, and the debate is not yet ended. The disputants, however, have all been evolutionists. Their differences have not been over the seriated features of evolution, but over the precise means by which the processes of heredity and variation are carried on. The total result has been to stimulate investigation and amass proofs of the development of one order of organisms from another throughout the entire history of life on the earth.

A fact established is consistent with every other fact bearing effective relation to it. Truth, like light, radiates in all directions. When, therefore, the vast array of evidence from the ever increasing collection of fossils, as well as from the classification and geographical distribution of plants and animals, past and present, demonstrated evolution by adaptation, it was inevitable that every other aspect of life would be in harmony with that principle.

If land vertebrates originated from amphibians having four legs, it was entirely consistent that their successors, except those which have lost some or all through reverse adaptation, should have four limbs, particularly as four have been enough for every form that ever existed. With these

four limbs and the spine, it was likewise consistent that all the species should be essentially similar in physical structure, the variations being those required by the different functions exercised. These facts have been shown so abundantly and in such minute detail that they need only be alluded to here. Nor need more than a mere reference be made to the blood tests which reveal the distant kinship of different species of animals descended from the same stock; nor to the remarkable results of variation produced by experiment and by the domestication of both plant and animals. Even more decisive, if possible, are the rudimental vestiges of organs and parts plainly reminiscent of functions active during remote stages of evolution, but long fallen into disuse. These are present in all higher animals and notably in the human species, which have no fewer than 180. Yet, as conclusive as these several lines of demonstration have been, the most striking phenomena are those displayed by the embryo of every animal form large enough to be studied in detail.

Like natural selection, embryology has been the subject of much controversy and with the same result: the processes are in debate, but the principle of evolution is confirmed in the most graphic manner. The most significant illustration is the human fœtus.

THE HUMAN EMBRYO

All animals, including the human species, begin in a single cell containing a nucleus. Starting in comparative simplicity, they develop into greater complexity. The human ovum or egg is about 125th of an inch in diameter; while the male or sperm cell that enters it and starts its development is very much smaller. This minute combination of living female and male matter holds all the characteristics of the future man or woman. During the first three months of fœtal development, all the great transformations take place. It is then that the human fœtus strikingly resembles that of the lower animals.

The fertilized ovum divides into two cells, these again divide, and this process of division continues, the cells definitely arranging themselves into tissues and organs. At about the third week the body cavities which enclose the organs begin to appear. The fœtus is then in the vermian stage. Having acquired a true body cavity, it becomes higher in construction than cœlenterate animals. In the second week the wormlike embryo begins to have a segmented body. In the following week four grooves appear in the neck representing the gill slits of fishes, while the heart also has the two-chambered form seen in fishes. Gills however, are not actually developed, but the structure shows a line of descent from ancestors among the fishes and amphibians. By the sixth week the gill slits have disappeared and the fœtus has passed to the lunged state. The heart then has the three chambers seen in the amphibia; gradually this becomes the four-chambered organ of the mammals, though it begins to beat at the two-chambered stage. The lungs are not used until birth, the placenta serving the purpose of respiration.[25]

THE CHEMISTRY OF LIFE

In Huxley's phrase, protoplasm is the physical basis of life. Despite the enormous amount of investigation and speculation devoted to the subject since Huxley's time, the general fact thus characterized has received little further explanation. The mystery has baffled chemical analysis and the microscope.

In this great field of the unknown lies the future of the most important research and discovery; and the prospect is the more encouraging because all the known elements of the problem are amenable to the methods of physical science. A glance at these features is needful in any exposition of the evolution of the brain, which in its physical character is similar to all other parts of the organism.

As water has been the most important agency in the transformation of the earth's surface and the liberation of

the chemical elements fused together in the igneous rocks, so it has been the chief vehicle of the organic chemistry by which life originated and has been maintained. Water is thus the basis of protoplasm, giving it the more or less fluid or colloidal character that enables it to utilize the chemical elements and compounds supplied to it. Inasmuch as water does not react with most biological substances, it promotes biochemical stability. Equally important is its dielectric constant, mentioned in a former connection, which renders it the best conductor of electric ionization in solution without disassociation of its own molecules. Its great surface tension furthers the capillary attraction so vital to plant growth. There can be no doubt that, however life originated, water was the medium.

At least twenty-nine of the chemical elements have been found in different living organisms; most of them, however, when present are in very minute proportions. The principal elements are hydrogen, oxygen, nitrogen and carbon. So important to life is carbon that organic chemistry is essentially the chemistry of its compounds, of which there are known to be over 100,000, probably exceeding those formed by all the other elements, while there are thousands of compounds of carbon, hydrogen and oxygen, and hundreds of carbon and hydrogen.[26] The vast majority of organic substances contain no other elements than these four. Phosphorous, sulphur, potassium, calcium, magnesium, iron and perhaps silicon are also present in all living organisms, except some of the most primitive bacteria, and are therefore regarded as essential to existing life. Besides these, chlorine, sodium, iodine and fluorine are commonly found as constituents.

It will thus be seen that the materials of life comprise most of the chemical elements of frequent occurrence in the rocks, the waters and the atmosphere. The metallic elements being charged positively and the non-metallic negatively, their action and reaction, through electrolytic ionization, are no doubt closely related to the activities of proto-

plasm; for they always take place in the presence of oxygen and with energy that comes directly or indirectly from the sun. Not only have no substances been found in organic matter except those familiar to chemistry, but no form of energy has been discovered in living things that is not derived from the inorganic world.[27] Yet back of all this are the mysterious powers of the heredity-germ which, from the beginning of life on the earth, has accumulated its peculiar powers over the definite organism it gives rise to, as well as perpetuating itself in its successors, with all those potentialities which have permitted the diversity of species since life originated in its first minute and simple forms.

The physical agency that causes or furthers the interaction or coördination of the parts of an organism, so far as known, is catalysis, in familiar use by chemists and on a large scale in some industries. A catalyzer hastens or retards chemical changes without being itself permanently affected. The mechanism of this action is unknown. The theory is that the phenomena are caused by the alternate attachment and detachment of the catalyzer to and from the substance upon which it acts. It is well known, however, that the enzymes are the principal organic catalyzers, different kinds acting upon different substances with different results; and all are produced by the organism itself. Their action is in a high degree specific and is therefore instrumental in accomplishing a great variety of effects necessary to the many organic functions, from the instant the system obtains air and sustenance to the final formation of tissues and the removal of waste.

The agents in general are styled chemical messengers, as they are discharged into the circulation of the blood and thus carried to the regions where they become effective. The simplest of them are by-products of single chemical reactions, such as carbon dioxide eliminated by the cells through breathing. This product, because of its acidic properties, is one of the chief regulators of respiration. The enzymes are far more complex. Their development appears to be

concurrent with the evolution of the organism as a part of its functional mechanism. They are supposed to reside in the nuclei of the cells, for the activity of the cell itself seems to depend upon them. The active agents of the external excretions are always in the nature of a ferment or enzyme. When an organism is invaded, elsewhere than inside the alimentary canal, by active foreign proteins, such as bacterial infection, the venom of snakes and insects and some vegetable poisons, they act as enzymes, causing chemical messengers, called anti-bodies, to arise for the protection of the tissues involved. The neutralizing anti-bodies are commonly known as anti-toxins. When the intruding protein (antigens) is not of an active order, the business of the anti-bodies is merely to remove the invader, without producing any degree of immunity from another similar attack. The function of curative medicines is, in like manner, to further the natural chemical processes of the body in counteracting the abnormal conditions caused by disease. The ductless glands are laboratories for the production of specific substances that pass directly into the blood stream with a stimulating, modifying or inhibiting effect upon other organs. Most of the vital and characteristic operations of the physical system, including the brain, are traceable to such activities. From such phenomena it may be fairly deduced that the interactions, of which these instances are typical, are the physico-chemical agencies which have been the alternating cause and effect of the very processes of evolution itself.

In the course of evolution the quality of its products has never been slighted. So ready is the response of nature to the requirements of life that whatever the functions to be served, the appropriate material, in perfect form and finish, is normally forthcoming to effectuate it. Each of the chemical life elements has peculiar properties adapted to those functions and freely enters into organic compounds for that definite service. When we consider the innumerable species of plants and animals that in the long cycle of evolution

have flourished and disappeared, we may form some idea of the inexhaustible resources of the elements that form organic compounds; for it is evident that the variety of substances composing them must have been fully as great as the number of species, if not many times greater. The plastic attributes of the inorganic elements that so wonderfully fit them to organic processes prompts the inference that life arose in response to universal laws of matter when the physical environment evoked their operation. All the facts now known point to the conclusion that organic powers and functions have evolved simultaneously with the forms they produced, proceeding from the simplest to the most complex. If this complexity, which finds its highest development in the human brain, has been the normal product of physical evolution, the volume of life automatically increasing with favorable conditions, the origin was probably due to the coöperation of peculiar conditions and the inherent properties of matter. Such is the gist of the argument of those who prefer to think that all the phenomena of life, like those of the inorganic world, are the result of law and not of supernatural intervention.

THE UNITS OF GROWTH AND FUNCTION

Cytology, the science of the cells, has made no radical advance since the discovery of the inheritance of definite characters in the primary cell (Mendelism) and the establishment of the theory that the chromatin (so called from its peculiar capacity for taking stain, which renders it distinguishable under the lens) constitutes the heredity-germ. Naturally all the resources of microscopy and chemical analysis have been directed unceasingly to the solution of the mystery; but all have been futile. Analytical chemistry can deal only with dead protoplasm after the subtle and elusive forces of life have ceased to act, while the infinitestimal minuteness of all structures lies far beyond the power of the microscope to reveal. "In recent years," says Eddington, speaking of gravitation, "great progress

has been made in knowledge of the excessively minute; but until we can appreciate the details of structure down to the quadrillionth or quintillionth of a centimeter, the most sublime of all the forces of nature remains outside the purview of the theories of physics." If the secret of gravitation be thus baffling, not less so are the problems of life, heredity and variation, and probably for the same reasons. Despite the enormous and unabated volume of speculation and controversy which these subjects have occasioned, we are no nearer to positive knowledge of the ultimate cause of these wonders than in Darwin's time, except as discussion has eliminated one theory after another from the babel of argument. "While we know," says Osborn, "the heredity chromatin to be the physical basis of inheritance and the presiding genius of all phases of development, we cannot form the slightest conception of the mode in which the chromatin speck of the germ cell controls the destinies of *Sequoia gigantea* and lays down all the laws of its being for its long life period of five thousand years. We are equally ignorant as to how the chromatin responds to these actions, reactions and interactions of the body cells of the life environment and of the physical environment so as to call forth a new adaptive character, unless it be through some infinitely complex system of chemical messengers and other catalytic agencies."[28]

New cells come into existence only by division of pre-existing cells. In a comparatively few cases the cell propagates by giving off a bud, which soon matures into a new cell; otherwise cell-reproduction is always through the equal division of an old cell into two new ones—the source of all growth and replacement in the higher plants and animals. Inasmuch as this process, known as mitosis, is observable in its larger aspects, the successive phases are well understood. Yet this knowledge lends no precise aid in solving the vital problem. We observe an infant grow into a youth, and the youth into a man; we know more or less of the physical agencies that enter into this development and

witness the physical changes they produce; but the mainspring of it all is undisclosed. As the man is but an aggregation of cells and their products, the problem remains where it was. However, as with evolution, what is known of the physical processes warrants the supposition that the unknown factors are of the same order, that is to say, normal and universal properties of matter under suitable conditions.

The unit of microscopic measurements is the micron, which is 1/1000 of a millimetre. Rutherford estimates that the diameter of the sphere of action of an atom is 1/10,000,000 of a millimetre. The most compact type of chromatin is that of the sperm-nucleus of the sea-urchin, estimated at about 1/100,000,000 of a cubic millimetre. As the electron is about 1/1800 of the mass of the hydrogen atom, the lightest known to science, the mass of the electron would be only 1/18,000,000 of a micron. Thus within the limits of the cell nucleus would be ample room for a multitude of mutually acting, reacting and interacting particles of matter, which constitute the source of life and direct the energies of the heredity-germ.

The difficulties in finding any concrete bases for speculation, owing to the ultra-microscopic nature of the underlying cell activities, are illustrated by the uncertainty as to whether any bacteria are the typical cell with its protoplasm and distinct nuclear chromatin. Bacteriologists (the word was not introduced until 1884) differ radically on all points, though they agree as to the presence of granules of the chromatin type, leaving as an open question whether or not there is a structurally distinct nucleus. In like manner it is unsettled whether protoplasm and chromatin originally appeared one before the other or both together.

No questions have ever been more suited to controversy than those relating to the origin of life and its fundamental processes, and the debate will doubtless proceed until some more tangible basis is found than has thus far been discovered. However these questions may be regarded, there is no doubt that the peculiar development of the brain cells

and the organ they constitute has been an evolution extending over the whole duration of life on the earth, and that the brain, with its attendant nervous system, has physically corresponded to the organism it accompanied and has been proportional in quality to the character of the activities it has regulated.

THE BRAIN A PHYSICAL EVOLUTION

A living thing composed of but a single cell, though of an animal nature, needs no brain or nervous system. The mere protoplasm of Protozoa is endowed with such sensibility to its environment and such perfect conductivity of effect that it is presumed to be the medium by which the nervous system of the higher animal organisms receives and transmits sensations. Why and how this is so is unknown. Sensations travel through a normal nervous system at a rate not exceeding 300 feet a second; but what it is that travels and how it travels—that is, the nature of the impulse—is still a mystery; the effects of sensations are well understood, but not what a sensation is. The mechanism and the impulse are manifestly of the same character in all animal organisms; the differences are of degree and not of kind. Thus the more complex the organism and the higher its functions, the more elaborate the system of communication and coördination and therefore the more intricate the constitution of the brain as the organ by which the interactions are regulated. All this has been demonstrated by anatomy and is in perfect accord with physiological theory.

The differentiation of the cells of necessity kept pace with the evolution of the Metazoa. In other words, the higher the organism the more complex the mechanism of its activities, the more various the materials entering into its structure, and therefore the greater the diversity of the cells to meet these manifold requirements. The nervous system and the brain were the organic response to the call of need. The evolution and adaptation of the cells to perform these functions are part of the mystery of life itself; and not less

profound than the secret of vitality is that of the capacity of the cell, as the organic unit, to perform its precise office wherever placed, while coöperating with the system of which it is a minute member, and obeying all the behests of the heredity-germ to which it owes its existence.

The intellectual functions of the brain are due to consciousness, the paramount attribute of mind that marks all higher animals, and in man forms the basis of all his vaunted faculties; yet what consciousness is, in the last analysis, is as inscrutable as what life is. The futile efforts to account for the phenomenon have produced most of the jargon of superstition and metaphysics. Nevertheless, some conclusions from known facts are warranted. Although the exact relation between the conscious mind and the brain is unknown, the mind (with all that the word implies) is absolutely dependent upon the activities of the brain as a physical organ; and proceeding a step further, the nervous system and the brain comprise the mechanism by which the external stimulations are transformed into organic behavior. The degrees of effective consciousness range from the simplest voluntary actions in lowly organisms to the highest flights of human genius. From these facts it is clear that consciousness itself is as much an evolution as the physical agencies that make it possible. And all the lesser degrees are present in every normal living person. There is, therefore, no true science of the mind apart from physiological psychology; yet knowledge of the physiology of the nervous system is very scanty. Relatively little is known concerning the nervous action of the brain. At the present time, even physiological psychology is little more than a series of neurological facts on the one hand and of facts of consciousness on the other.[29]

The functions of the various organs are, for the most part, automatic. We are unconscious of their action, unless they are involved in some abnormal condition such as injury or disease, that causes disturbance of the tissues and their communicating nerves. The progress of modern physiology

has been largely due to the discovery of the physico-chemical offices of the glands of the system, of which the most expert were formerly ignorant; and the subject is still far from exhausted. The fundamental processes of life are automatic; and it is because they are so highly ramified, so nicely adjusted, and so obscure withal, that surgery as a science is so far in advance of medicine. Diagnosis is too often a misguided guess, while the knife exposes the condition. The circulation of the blood was not generally recognized until toward the close of the seventeenth century; and the complicated properties of the blood are still an increasing source of discovery in the field of biology and the treatment of disease.

During antiquity and when the Greeks formulated their philosophies the seat of the mind was variously located in the liver, the kidneys, the heart and elsewhere, rather than in the brain. Plato thought the marrow of the bones the likeliest place, to the derision of Aristotle, who nevertheless supposed that the purpose of the brain is to regulate the temperature of the blood; and the influence of his teachings was very great until the progress of science began to displace the notions which had so long prevailed. During the centuries when theology and metaphysics were most industrious in defining the nature and destiny of man, primarily because of his intellect, the functions of the brain were mostly unknown. In fact it was not until the middle of the nineteenth century that the foundation was laid for a scientific psychology.

Physical coördination was necessarily long before conscious action was even elementary. This is shown by the autonomic nervous system, which lies outside of the spinal column. It is connected, of course, with the cerebro-spinal nervous system, but is relatively independent, controlling respiration, circulation, digestion and glandular action, which are automatic. The system, in various forms, was present in all animal organisms above the very lowest before the Vertebrates appeared. Obviously the spinal cord

and its branches were not less important in the evolution of the Vertebrates than the spine itself. Yet physical organization and power reached their highest development far in advance of mentality. In the gigantic reptiles, in which brain evolution was in a primitive stage, the coördination of the limbs was evidently reinforced by a sort of relay station—a sac of spinal fluid or nerve substance in the sacrum, the region of the vertebræ sustaining the monstrous tail and huge hind legs.

If specimens of the brain at the different stages of its evolution were available they would add but little to the knowledge derived from the known forms and activities of extinct animals and the shapes and capacities of their brain-cases. Moreover, among existing orders the progressive stages clearly confirm the theory of mental evolution. The facts are so well established that the general process is represented by the chief characteristics of this development in the brains of the higher mammals.

The disparity between the brain-power of the highest reptiles and the earliest mammals was not greater than between that of the archaic mammals and their remote descendants. Different habits, varied adaptation of tooth structure to the foods consumed and increase in size as well as flexibility and power of movement required and produced corresponding brain development; and the rapidity of mammalian evolution as compared with that of other types was due to this mental improvement in many directions. As a large proportion of the mammals, then and later, were carnivorous, the most physically fit had the advantage, and the inferior succumbed. Likewise, the herbivorous orders developed powers of alertness, speed and agility as their best defense against rapacious foes. The gradual development of these physical characteristics was necessarily attended, as a part of the process, by corresponding changes in the nervous system and the brain. Thus the brains of succeeding species of the progressive orders increased in size and functions. Many series of skulls of dif-

ferent types very graphically exhibit the extent and character of this development.

THE MECHANISM OF THE BRAIN AND NERVOUS SYSTEM

Throughout the entire range of the phenomena of sensation, from the lowest forms of animal life to the highest, the mechanism is of the same character and operates by the same forces. The evolution of the human brain is traced through many successive stages precisely parallel with the evolution of animal form and organization. In all Vertebrates, from fishes to man, the nerve masses originate in the outer part of the blastoderm, the living portion of the ovum from which the embryo and all its membranes are derived. At first three and subsequently five consecutive brain-vesicles are formed by expansion at the first section of the spinal cord. From these vesicles the greater divisions of the brain, with all their complicated incidents, are developed. The course and character of the development necessarily differ with the nature of the organism, but in man and the apes the analogy is very close.

The first vesicle becomes the cerebrum; the second, the optic thalamus; the third, the corpora quadrigemina; the fourth, the cerebellum; and the fifth the medulla oblongata. The cerebrum steadily overlaps and finally covers the cerebellum, which develops slowly, the lateral lobes at the expense of the middle one. As the cerebrum increases in volume the surface begins to fold, producing convolutions and fissures, which give the position of the different orders in the organic scale. In man they reach their highest evolution in number and complexity. In its earliest stages, the development of the brain, like that of the organism, is similar in all Vertebrates. In the succeeding stages extensive modifications take place; but even here the brains of all mammals, bear resemblance in structure, the departures from the common form corresponding to the grade of intelligence possessed by the animal. The division of the brain into two hemispheres is characteristic of the organ wherever it ex-

ists, and of course becomes more distinct with the higher development of its functions. The separation, however, is not complete. The two parts are united by a broad band of fibres called the corpus callosum; yet the fissure extends the entire length of the cord and divides it in halves.

From the base of the human brain twelve pairs of cranial nerves extend. Some carry only sensory fibres, some only motor, and some carry both. As the name implies, the sensory nerves relate to the consciousness; the motor, to the various organic functions that are more or less automatic. From the spinal cord thirty-one pairs extend, each nerve being attached to the cord by two roots. One is composed chiefly of sensory fibres from cell bodies of the spinal ganglia; the other, of motor fibres the cell bodies of which lie within the gray matter of the spinal cord. The two unite after leaving the cord and form a complete spinal nerve. These pairs of nerves are distributed along the entire length of the spine, and their innumerable extensions and ramifications complete the cerebro-spinal nervous system.

The nerve cells, called neurones, are the units of the nervous mechanism, which is the most complicated thing in nature. Their importance in the physical system may be inferred from their number, estimated at some ten thousand million in every adult person, every neurone being in itself a complex organ capable of many connections. They are present throughout the brain and all the tissues. The general scheme of this immensely complicated system may be gathered from the principal features.

The neurones are of three classes. The sensory or afferent bring stimuli to the brain and spinal cord; the motor or efferent carry stimuli from these centers to the muscles; and the associative or central, comprising the elaborate mechanism—the greater part of the brain—by which the sensory and motor neurones are connected, thus controlling and coödinating the functions of the organism. Those which cross from one-half of the brain or cord to the other are termed commissural. "Even if we knew," says Thorndike,

"the exact arrangement of each neurone in a man's brain, it would take a model as large at St. Paul's Cathedral to make them visible to the naked eye."[30]

The distinguishable peculiarity of the neurones is that the enlarged portion, containing the cell nucleus and possessing the ordinary properties of other cells, is only a part of the unit which includes threadlike prolongations and branches that terminate in a number of minute strands like the frayed ends of a string. The fine-spun terminals of the sensory neurones serve the purpose of gathering the sensations conveyed to the other parts. The cell body operates in most cases to reinforce and regulate the impulses brought from the extremities and passed on in transit to the brain. The motor neurones perform the converse function of carrying the governing impulses from the brain to the muscles. With all this maze of nervous apparatus, intimately connected and perfectly adjusted, in normal conditions, is an almost equally wonderful conjunction with the physiological processes by which the organism is sustained and activated; and all this without regard to the nature of the organism, the differences being in detail and not in essential character or method.

The white appearance of the greater part of the brain texture, the cord and the nerves is due to the medullated sheath of the nerve fibres. The gray matter is the true nerve substance and constitutes the cortex or outer layer of the brain, certain ganglia within the brain and the core of the spinal cord. The cortex is of course protected by membranes from contact with the skull. The physiological character of the human brain and its kinship with the mental mechanism of all other animals is evident without detailed description of its parts. Some further reference, however, to the cortex, which contains all the centers of the mental processes, is necessary.

The most remarkable and inexplicable characteristic of the cortex is the apparent absence of any of the conscious functions from one of the hemispheres. Usually the left half is the active one; yet to all appearances the two are

perfectly matched. The dispositions of gray matter in them correspond fissure for fissure, lobe for lobe, and convolution for convolution; and these also agree in every particular except for some differences in size and shape, with the brain of the chimpanzee. With other higher animals the parts of the brain are perfectly analogous, exhibiting the same general conformation and arrangement, composed of the same materials and operating in the same way. The differences in form are only such as are produced by the differences in the functions served. The mysterious attributes of the human brain exist alike in the brains of all other animals. These facts are not to be ignored in any consideration of the human intellect. To disregard them is to proceed upon assumptions for which there is no scientific warrant.

The neurones of the cortex are arranged in strata, each stratum containing those of a characteristic type. The thickest stratum holds neurones of a pyramidal form, pointing toward the surface. They are associated with the higher mental processes; and the degree of intelligence, in both man and animals, depends upon the size and number of these cells and their appendages. The number in the brain of the human fœtus increases until the third or fourth month, when the limit for the individual is reached. After that time the only changes are in their structure and in the length and complexity of their branches. The ultimate quality and calibre of every brain are therefore fixed before birth and are governed by the precise character of the physical structure. The cause of many psychological phenomena was only surmised until it was fully demonstrated by exact investigation of many types of brain, human and other.

The sensorial, language and associational centres are normally located in the left hemisphere. Cases have been known where disease has practically destroyed the gray matter of the right hemisphere, together with the corpus callosum, which connects it with the left, without directly affecting the faculties, but producing paralysis of the right

side of the body. From such evidence it is manifest that the right hemisphere, while without the purely mental functions exercised by the left, nevertheless contains motor areas which control extensive muscular action. On the other hand, lesions of various parts of the left cortex, caused by injury or disease, always involve corresponding loss or impairment of function. These consequences have enabled psychology to map the active cortical hemisphere with certainty as to the senses, language and the principal faculties. This index, however, is not to be confounded with the fanciful notions of phrenology, which have no tangible basis whatever.

The functions of very considerable areas of the cortex both in the pre-frontal regions and elsewhere, adjacent to known centres, have not been determined. Inasmuch as all the higher intellectual faculties are associational, these parts are supposed to be the seat of the complex adjustments and correlations essential to those operations. At all events, there is no reason to doubt that the intellect, in its highest powers, is as distinctly physical in its action as any other feature of mentality.[31]

THE SOURCE OF THE SENSES

All the sense organs have been developed from the integument and have nerves connected with them. This is the common bond which unites the entire kingdom down to Protozoa, which have no differentiated sense organs, but receive sensations over all parts of the surface. Thus the sense of touch in the most primitive. Organs for the perception of light were next in the order of evolution. The eyes of all vertebrates have essentially the same system of integument and nerve elements. The evolution of the eye and the visual sense is readily traced from a simple pigment spot to the highly complicated eye structure and vision of the Vertebrates and man. As the eye was produced by the integument in response to vibrations of the ether, so the sense and organ of hearing were produced in response to the vi-

brations of the air. Very little is yet known concerning the physiology of smell and taste. Both functions have arisen in answer to the needs of the animal organism through the action of material forces. The associational system by which all the impressions received by the brain are adjusted is equally obscure.

Such are the salient facts of psychology regarded as the climax of physiological evolution; and such is the basis of the vast mass of speculation and dogma to which the nature of the human mind has given rise. It may be confidently assumed that the solution of many of the mysteries that now baffle the understanding is more promising in the field of physiology than in the domain of philosophic disputation.[32]

THE EVOLUTION OF SOCIETY

About the same proportion of mere hypothesis to the body of observed facts in the science of psychology obtains in sociology, the science of society. The temptation to speculation and the motives for dogma are about the same in both. As the mind gives character to the individual, so the average of its units gives character to society. If the mind is the reflex of material conditions and human activities are circumscribed by them, the individual and society should conform to principles perfectly adjusted to them. This conclusion would seem to be the logical and necessary result of the nature of man so far as science has been able to determine it from the physical elements of the world in which he lives and of which he is a part. This conclusion involves certain limitations and great difficulties of application, especially in minds unwilling or unable to accept the physical evidence.

It is clearly as much the function of science to disclose the elements of human conduct as it is to explore the material environment and reveal the constitution and nature of things. The ultimate purpose of science that justifies its development in the past and its promise of future service is the benefit that accurate knowledge must bring to the course

of civilization. It is not proposed here to venture upon any philosophic discussion, but the survey we have now made of the physical conditions of our world and ourselves warrant some general observations upon the material aspects of the greater human problems.

In contemplating the rise of the human species with the potentialities of mind which have made possible the human intellect at its best, and regarded solely upon the evidence as a physical evolution, one is prompted to inquire whether any feature of human history reveals anything more than a natural part of the process. The most prominent fact in human evolution is the relation of the quality of intellectual development to the accumulation of experience. There can be little question that in mere capacity the average brain of the Cro-Magnon some 25,000 years before the beginning of the historic period was fully equal to that of the present time. The skeletons and skulls of those races indicate that in physique they were not inferior to any living race, and that the brain as a physical organ had attained its characteristic form and functions. This is the most fundamental fact in considering the nature and extent of human progress. It is in harmony with sound psychology and reconciles the facts of history with the principle of evolution.

The slow progress from the period of sheer savagery, when the race first began to use weapons and utensils rudely fashioned by accidental means, to the establishment of the original centers of civilization was due to the gradual changes in the structure of the brain corresponding with the functions arising from increased experience. And it is significant that the process was similar to that which marked all other forms of organic evolution. For example, the Neanderthal type does not appear to have changed much in body or brain during the many centuries of its dominance in Europe. It was evidently displaced by a higher type originating elsewhere and making its way by reason of mental superiority. How such new types arise is a matter of controversy; but it is generally conceded that, in some cases at least, they do

occur by mutations. The history of ancient civilization, like that of modern times, shows that highly gifted minds appeared at intervals and exerted a vast influence upon their surroundings. Such influences brought new experiences and improved or altered social conditions, which of course reacted upon adjacent communities and succeeding times.

This factor of racial progress during the early phases of civilization is especially prominent because of the relatively long periods they covered and the restriction of the record, in the main, to such public events as wars, revolutions and royal succession. The historical methods that now prevail are distinctly modern; and the application of them to the revision of ancient history by utilizing the economic and social elements that formed the background of the more conspicuous public events emblazoned in the chronicles is one of the most striking indications of the pervasive scientific spirit in which all the conditions of human activity have come to be regarded.

The results of this recasting and amplification of ancient and medieval history according to the standards of actual experience in modern times and in the light of scientific principles have been to demonstrate the evolution of thought as reflected in manners, customs and institutions. In perfect analogy to physical evolution throughout geologic time, this progress has been fitful and sporadic. When conditions favored progress an advance occurred—now here, now there, but always adding to the total of experience and thus to the momentum which in the long run has been superior to the immediate obstacles. No historical narrative better exhibits the principles of social evolution than Gibbon's *Decline and Fall of the Roman Empire.* Although written in the last quarter of the eighteenth century, when modern science was in its initial stage, the work is entitled to rank as the greatest single contribution to descriptive sociology. Here may be found the most remarkable series of events and conditions in human history, disclosing phenomena of all the principal types, thus affording a basis of comparative anatomy, so to

speak, by which to study the evolution of the social organism and to aid in diagnosing its existing ills.

The most powerful and constant influence in human history has been the general belief, in one form or another, that supernatural agencies operate in the affairs of mankind. This influence has been effective in proportion to the degree of popular ignorance of natural conditions. The fact that from aboriginal and prehistoric times the great mass of human beings have sought explanation of the unknown in the supernatural has been accepted as proof of the principle. An appeal to elementary psychology should refute this conclusion.

It was inevitable that when the mind arrived at the stage of conscious intelligence it should ask the questions Whence and Whither? Every normal child does so, very early in the course of its mental development. Any race of human beings that failed to do so would have been abnormal and mentally defective, whatever the stage of its evolution. It was equally natural and inevitable that, in the absence of knowledge, the conception of supernatural power as the explanation of mystery should arise. The idea, therefore, proves nothing; and the prevalence of it has gradually diminished as the frontiers of the unexplained have receded.

The development of society from the tribal form to modern nationality is as clearly an evolution as the race itself. That the process is far from complete renders the subject of profound interest as the crowning problem of scientific thought. The greatest and most deviously persistent obstruction to an ideal form has proceeded, directly or indirectly, from the fundamental vice—adherence to ideas, mostly theological, that took root in the superstitions arising from ignorance of the causes of natural phenomena. Religious wars and forcible religious propaganda and repression as a factor in human affairs have ceased, except in some relatively small regions which have not as yet felt the full force of the conditions that prevail in more enlightened nations. But the retarding effects of such ideas are still very prev-

alent indirectly. Cults and creeds based on any form of superstition or dogma inevitably seek power and either aggressively or insidiously affect political institutions. These influences are rife and everywhere more or less powerful.

Since the American and French revolutions, the idea of the divine right of royal rulers has been steadily waning. Perhaps the most important effect of Napoleon's career has been to hasten its expulsion. In the Germanic empires the principle was sedulously fostered and thus formed the basis of the unquestioning loyalty and obedience of the masses to the behests of imperial policy. Rulers who assert themselves to be divine representatives necessarily assume that their opinions are conclusive, their prerogatives supreme, and their territorial expansion justified whatever the means. Such rulers would have been quite helpless without some delegation of their prerogatives and powers; hence arose the nobility and privileged classes, who were likewise beneficiaries of the popular illusion.

Victor Hugo's observation at the close of his description of the battle of Waterloo, that Napoleon failed because he was not in harmony with the nineteenth century, applies to the teutonic attack upon the principles of civil liberty. The Prussian Kultur was not in accord with the twentieth century—with the course of evolution which has brought mankind to its present status. It is enough to remark that at no former period would it have been possible for the more advanced nations to combine for the assurance of the principles that underly their civilization and that must eventually develop social, economic and governmental conditions giving proper scope to the powers and rights of individuals as the units of all institutions.

With the complete suppression of the archaic forces that caused the conflict, the world will enter upon a new sociological era as clearly defined as any of the stages of organic evolution. Yet it would be rash prophecy that ventured to specify the results of the new conditions that will have arisen. Those conditions will be plastic and embrace a com-

plexity of elements that have never been operative in many nations where centralized government and inveterate customs and habits of mind have determined and limited their action. Even in pre-existing republics the exigencies of war compelled the exercise of powers that would have been resentfully denied in normal times. The situation thus created cannot long endure. The return to conditions of peace has already brought with it new ideas and purposes engendered by the extraordinary experiences through which civilization had passed even in those countries where the effects of the conflict are only indirect. Efforts to realize those objects will provoke political activity in which forces long latent will assert themselves. It is probable, therefore, that in the distant future of civilization the twentieth century will take rank in the scale of social evolution with the Tertiary in the evolution of life.

These considerations supply the practical reasons why education should invariably and systematically include instruction in the fundamental sciences as the basis of all other teaching after children have learned to read and write. Opinions and beliefs formed in ignorance of the natural causes through which the world has been brought to its present physical condition, of the nature of man and mind and the true functions of political institutions, inevitably react and form the chief obstruction to progressive ideas.

The great events of history, in all their variety, have been in the main but episodes in the evolution of social conditions. Yet this evolution as reflected in the science of government and administration has not been commensurate with the efforts expended to establish true principles. The obstacles have been too various and too deeply rooted in custom and power long exerted to yield readily to ideals which have not been in agreement. Nevertheless, the general and fundamental principle of popular sovereignty has made such wide and steady progress that the phase of absolutism, however disguised or diluted, is approaching its end.

All this is the result of materialism in its highest sense, which is not to be confounded with the narrow one sought to be imposed upon it by those who assert supernatural agencies in human affairs. In this sense materialism signifies natural results from natural causes, excluding any other explanation of phenomena. The action of natural forces depends solely upon the physical conditions in which they operate. Heat, for example, when controlled, supplies comfort and service; unchecked, it destroys. Throughout the whole realm of life and mind this familiar principle holds true.

Materialism, then, in its true sense, is knowledge of natural forces and intelligent control of them. Weapons of war in the hands of the foes of progress must ever be met in kind and overcome by superior force. But the gravest dangers are in stealthy reaction, and the ranks of reaction are always recruited from the uninformed and seek justification in oppressive conditions. The greatest measure of civilization will not be achieved until justice, the morals of society, is established among nations and among all the elements of every nation. Such is the prospect of ultimate evolution. Such is the promise of science.

THE END

NOTES

Most of the following notes are offered as a guide to readers who may desire to pursue further some of the more important topics presented by the text. In a work of this kind references are unnecessary. All statements of fact may be taken as justified by standard works in the several divisions of science to which the facts relate.

1. In 1916 a star was discovered somewhat nearer than Alpha Centauri, to which it appears to have some relation, possibly that of a third member of a system long supposed to be binary. Proxima Centauri is dark red and very faint, being of about the 11th magnitude.

2. *The Evolution of the Stars and the Formation of the Earth,* by W. W. Campbell, a series of lectures before the National Academy of Sciences, published in *The Scientific Monthly,* September-December, 1915. *An Introduction to Astronomy,* by F. R. Moulton, will supply a more detailed view of the general subject. *The Binary Stars,* by R. I. Aitken, is a recent and valuable contribution to the subject of stellar evolution.

3. Lowell's principal books, *Mars and Its Canals, Mars as an Abode of Life* and *The Evolution of Worlds* will repay attentive perusal. They are models of "popular science."

4. The physical arguments that life exists on Venus and does not exist on Mars are set forth in *The Destinies of the Stars,* by Arrhenius. This volume contains many suggestive considerations as to various cosmic problems.

5. *What We Know About Comets,* by W. W. Campbell, in *The Scientific Monthly,* December, 1916, gives an authoritative account of these objects; and *The Story of the Comets,* by G. F. Chambers, the history of their visitations.

6. *Meteorites: Their Structure, Composition and Terrestrial Relations,* by O. C. Farrington.

7. "The difference," says Sir Joseph Thompson, "between the laws of gravitation of Einstein and Newton comes only in special cases. The real interest of Einstein's theory lies not so much in his results as in the method by which he gets them. If his theory is right it makes us take an entirely new view of gravitation. The weak point in the theory is the great difficulty of expressing it. It

would seem that no one can understand the new law of gravitation without a thorough knowledge of invariants and of the calculus of variations. One other point of physical interest arises. Light is deflected in passing near large bodies of matter. This involves alterations in the electric and magnetic fields outside of matter—forces at present unknown, though some idea of their nature may be got from the results of the eclipse expedition."

All science has hitherto been based on the Euclidean system of geometry. That system assumes that all measurements are from the rigid data by which plain areas and cubic content are calculated. Newton's law of gravitation is based on that geometry. The theory of Relativity depends upon a system of geometry that calls for a fourth dimension—the "time-space manifold." This is calculated only by super-mathematics; and it imports a difference in results so minute as to be ascertainable only for astronomic distances. It therefore does not enter into consideration as to any of the ordinary subjects of physical science.

The theory has yet a hard road to travel before it can gain general acceptance by men of science; but it will doubtless aid in a better understanding of the ultimate forces of the universe. A very intelligible exposition of it is set forth in a lecture of Edwin B. Wilson, *Space, Time and Gravitation,* published in *The Scientific Monthly,* March, 1920.

8. *The Sun,* by C. G. Abbott. The details of the organization of the Solar System are given in Moulton's *Introduction to Astronomy.*

9. The Planetesimal Hypothesis is fully presented in *The Origin of the Earth,* by T. C. Chamberlin.

10. *Elements of Geology,* by W. H. Norton, gives in a clear and concise form a good knowledge of both branches of the science.

11. *An Introduction to Historical Geology,* by W. J. Miller, is an excellent work suited to the general reader.

12. *The Old Red Sandstone,* by Hugh Miller, should be read. This classic is valuable not only as showing the pleasure and profit of geological studies in the field, but the tenacity with which early naturalists clung to the idea of special creations.

13. In relation to the Cretaceous, Huxley's lecture, *On a Piece of Chalk,* in his *Lectures and Lay Sermons,* should be read.

14. *A New Era of Chemistry,* by H. C. Jones.

15. *Chemical Discovery and Invention in the Twentieth Century,* by Sir William A. Tilden.

16. *The Electron,* by R. A. Millikan.

17. *The Nature of Matter and Electricity,* by Comstock and Troland; *Outlines of Theoretical Chemistry,* by F. H. Getman.

18. *Paleontological Evidences of the Antiquity of Disease,* by R. L. Moodie, *The Scientific Monthly,* September, 1918.

19. The reptilian origin of the mammals is still disputed. The argument in support of the amphibian source is given in Chapter XVII of *The Causes and Course of Evolution,* by J. M. Macfarlane.

20. *Evolution and Animal Life,* by Jordan and Kellogg; *Organic Evolution,* by R. S. Lull; *The Age of Mammals,* by H. F. Osborn.

21. *A History of the Warfare of Science with Theology,* by Andrew D. White.

22. *Men of the Old Stone Age,* by H. F. Osborn.

23. *The Origins of Civilization,* by J. H. Breasted, a series of lectures before the National Academy of Science, published in *The Scientific Monthly,* October, 1919-February, 1920.

24. The best and most authoritative account of the idea of Evolution is *From the Greeks to Darwin,* by H. F. Osborn. Darwin's influence in all the main departments of science since his time is well displayed in *Darwin and Modern Science* and *Fifty Years of Darwinism,* each a symposium by eminent scientists, published in 1909 in commemoration of the centenary of Darwin's birth.

25. *Text Book of Geology,* by Pirsson and Schuchert, page 963.

26. *Outlines of Organic Chemistry,* by E. J. Moore.

27. *Creative Evolution,* by H. Bergson, illustrates the futility of attempting the advance physical science by philosophic disquisition.

28. *The Origin and Evolution of Life,* by H. F. Osborn; *The Causes and Course of Evolution,* by J. M. Macfarlane; *The Evolution of the Earth and Its Inhabitants,* by Professors Burrell, Schuchert, Woodruff, Lull and Huntington, of Yale University.

29. *Psychology,* by B. B. Breese.

30. *The Elements of Psychology,* by E. L. Thorndike. The illustrations in this volume are a most valuable feature.

31. *Brain and Personality* and *What Is Physical Life?,* by W. H. Thomson, are valuable to the general reader. The facts presented are culled from the author's extensive professional experience. Strict logic, however, leads to conclusions quite different from those reached by him.

32. The relation of man to other animals, in physical and mental evolution, is fully demonstrated in *The Human Species,* by L. Hopf. The value of Huxley's classic, *Man's Place in Nature,* has never been impaired.